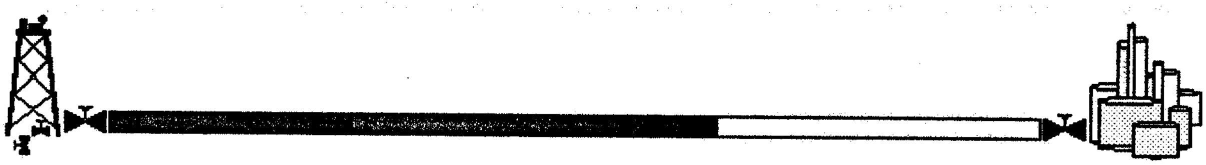
PIMPIS: Knowledge-Based Pipeline Inspection, Maintenance & Performance Information System

Meeting Notes



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June 97

254 B

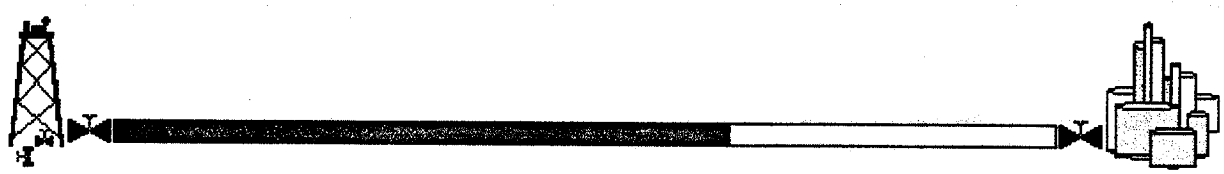
Knowledge-Based Pipeline Inspection, Maintenance & Performance Information System (PIMPIS)

Project Progress Meeting
Friday June 27, 1996
Room 214, McLaughlin Hall
Berkeley, CA 94720

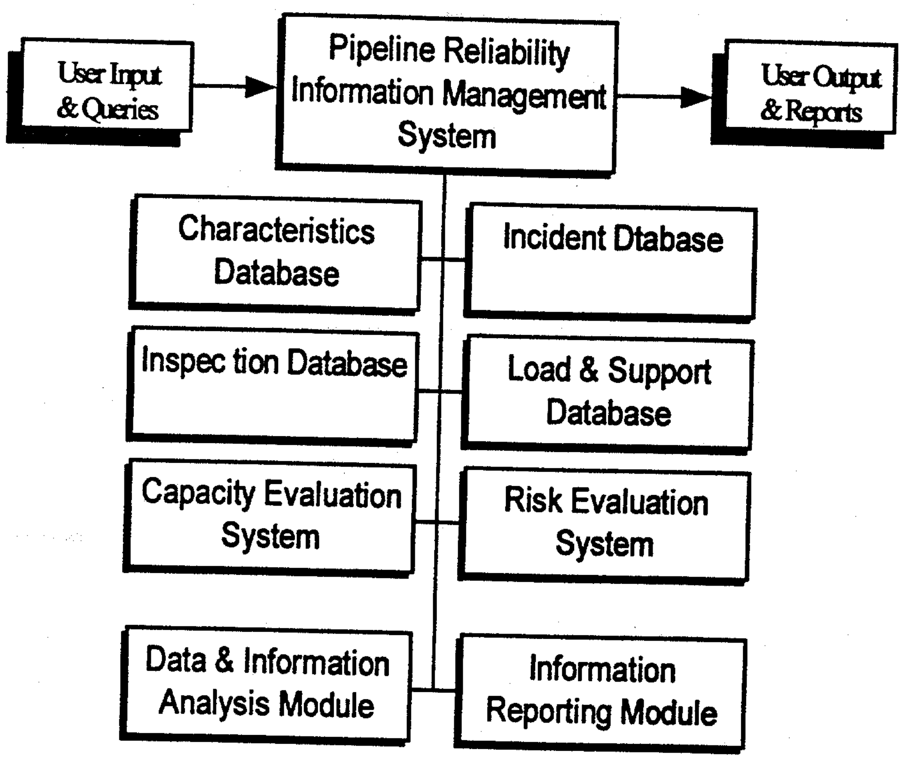
AGENDA

9:00	**Introductions: Meeting & Project Objectives.** *Bob Bea*
9:15	**Analysis of Offshore Pipeline Failure Data: Gulf of Mexico OCS Region.** *Tarek Elsayed*
10:15	**Coffee/Stretch Break.**
10:30	**Developments in Qualitative Pipeline Risk Assessment.** *Tarek Elsayed*
11:15	***Discussion***
12:00	**Lunch**
1:00	**Inline Inspection: Standardization & Reliability issues.** *Yohannes Rosenmoller, HRE Rosen Engineering*
2:00	**Discussion/ Sponsors Input**
2:15	**Stretch Break**
2:30	**Reliability Analysis of Corroded Pipelines: A Quantitative Approach** *Tarek Elsayed*
3:15	**Demonstration of PIMPIS Software development** *Tarek Elsayed*
4:00	**Discussion/Sponsors Input**
4:30	**Adjourn**

Analysis of Offshore Pipeline Failure Data: Gulf of Mexico Outer Continental Shelf Region



Structure of Pipeline Inspection, Maintenance, and Performance Information System (PIMPIS)



Analysis of Offshore Pipeline Failure Data

- The failure frequency of offshore pipelines is an essential ingredient in many types of managerial decisions including:

  1-Assessment of risks from leaks.

  2-Evaluating the effectiveness of inspection and maintenance policies.

  3-Allocating funds for repair, replacement and rehabilitation.
- The motivation for this section described here was to perform a more in-depth evaluation of the pipeline failure data for the Gulf of Mexico than reported earlier using an extended MMS database for the period 1967-97 and to compare the results with those reported earlier by different authors.
- This section presents an overview of causes and frequencies of failure of offshore pipelines handling petroleum and natural gas.

Analysis of Offshore Pipeline Failure Data

- The evaluation results presented here provide an improved basis for assessment of safety of pipelines and for further improvements to current pipeline design, inspection, maintenance and failure data collection procedures.
- Two databases have been analyzed:

  1- The MMS database: covering pipelines in the OCS region (1967-97).

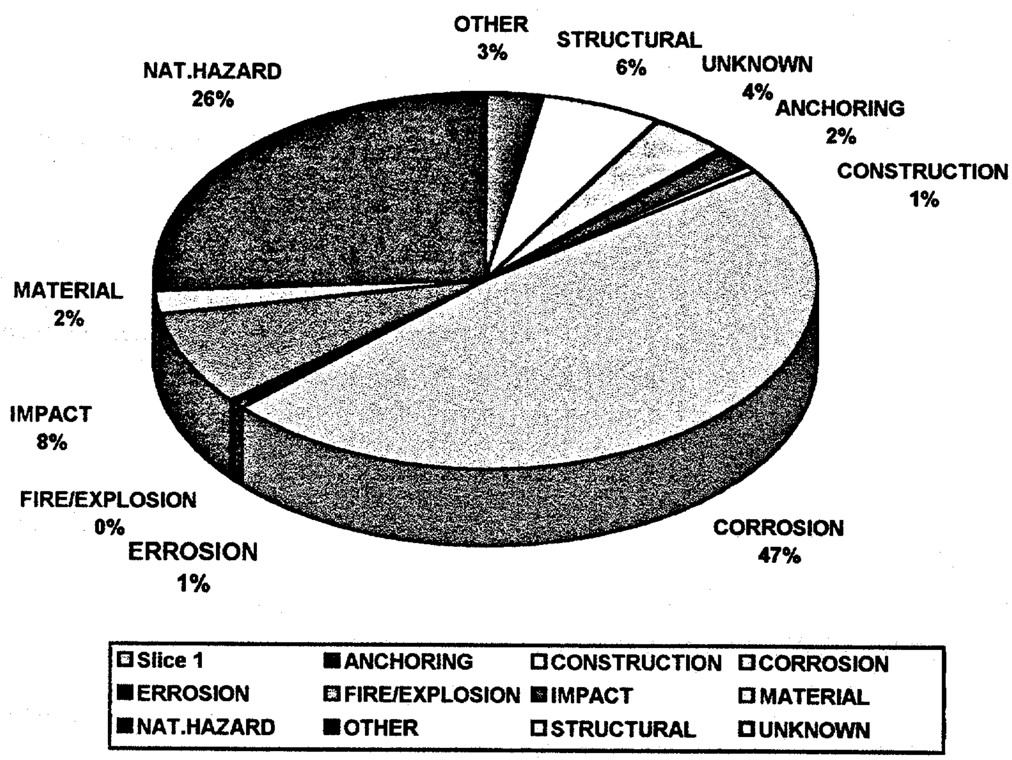
  - A pipeline database: which contains details of pipelines installed in the Gulf of Mexico.
  - An incident database: which contains a description of reported incidents and data on the pipelines affected.

  2- A Coast Guard database (1990-97)

  covers pipelines in state waters.

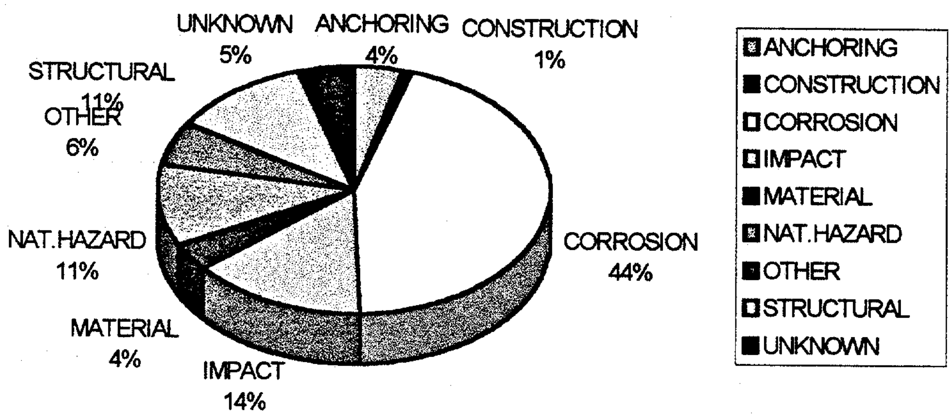
  - An incident database: which contains a description of reported incidents and data on the pipelines affected in state waters.

Pipeline Failures By Cause
Gulf of Mexico: OCS Region
Source: MMS Database 1967-97

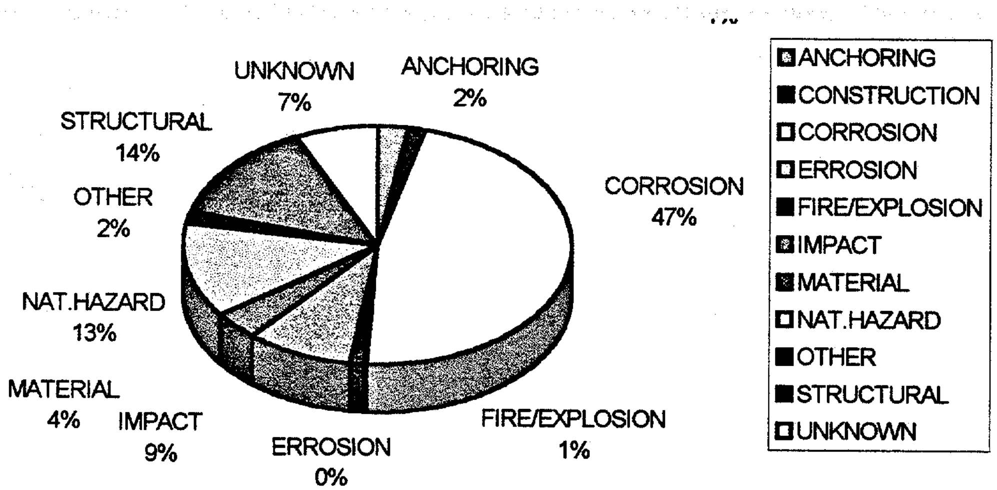


Pipeline Failures By Cause: Different Pipe Categories Source: MMS Database 1967-97

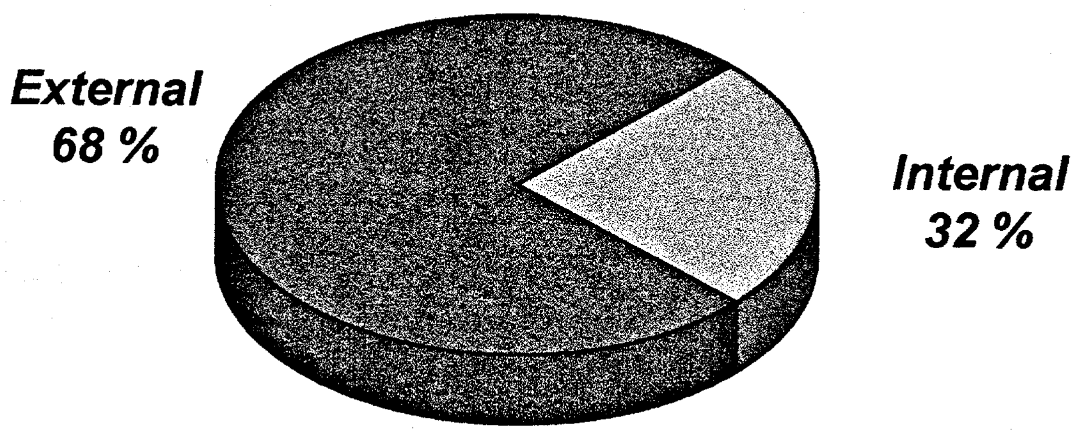
Oil Pipelines



Gas Pipelines

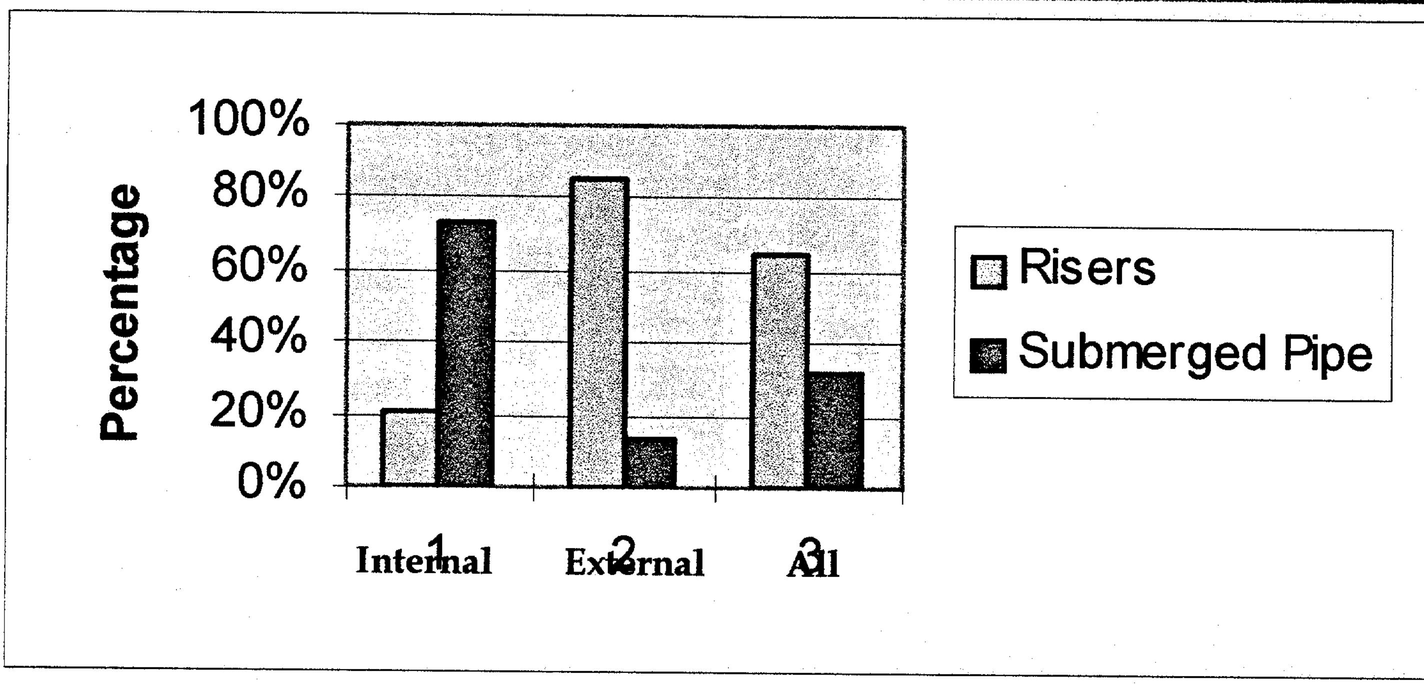


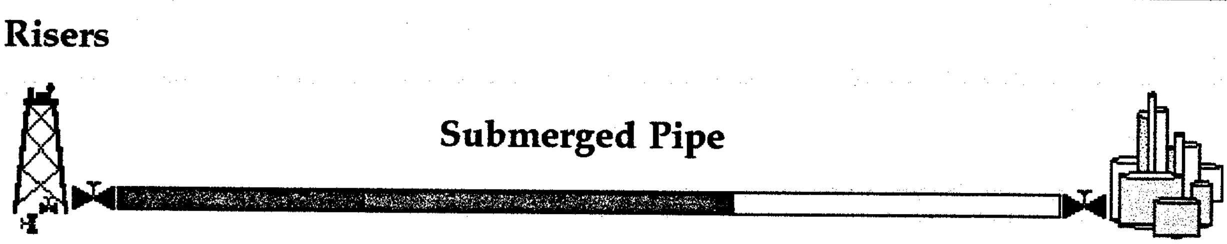
Corrosion Failures
Gulf of Mexico: OCS Region
Source: MMS Database 1967-97



Total Number of Internal Corrosion Failures =362
Percentage of Total Failures =15.36 %
Total Number of External Corroaion Failures = 759
Percentage of Total Failures = 32.64 %

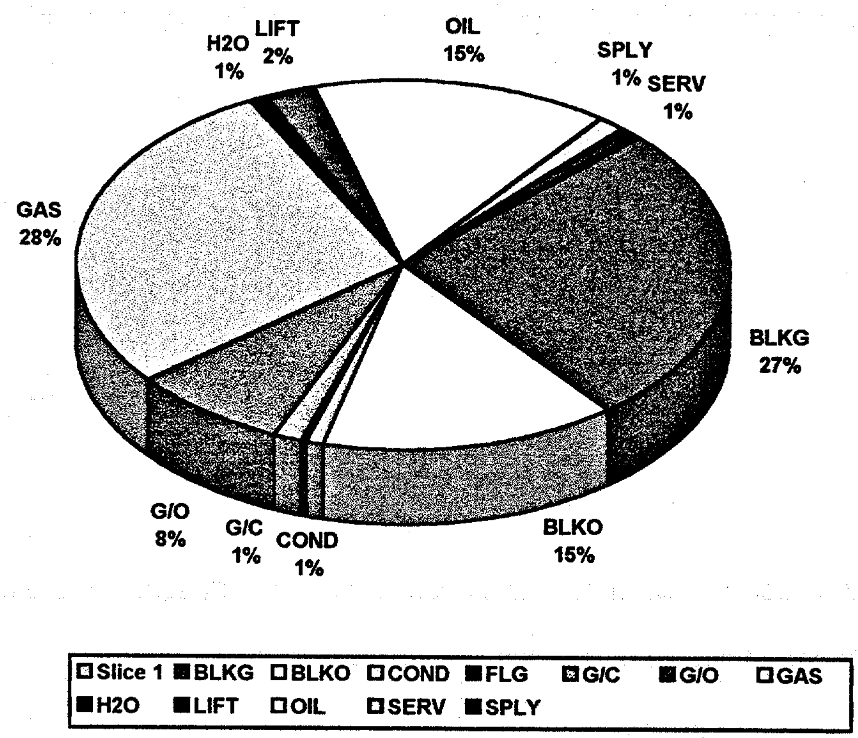
Corrosion Failures By Location
Gulf Of Mexico: OCS
Source: MMS Database 1967-97



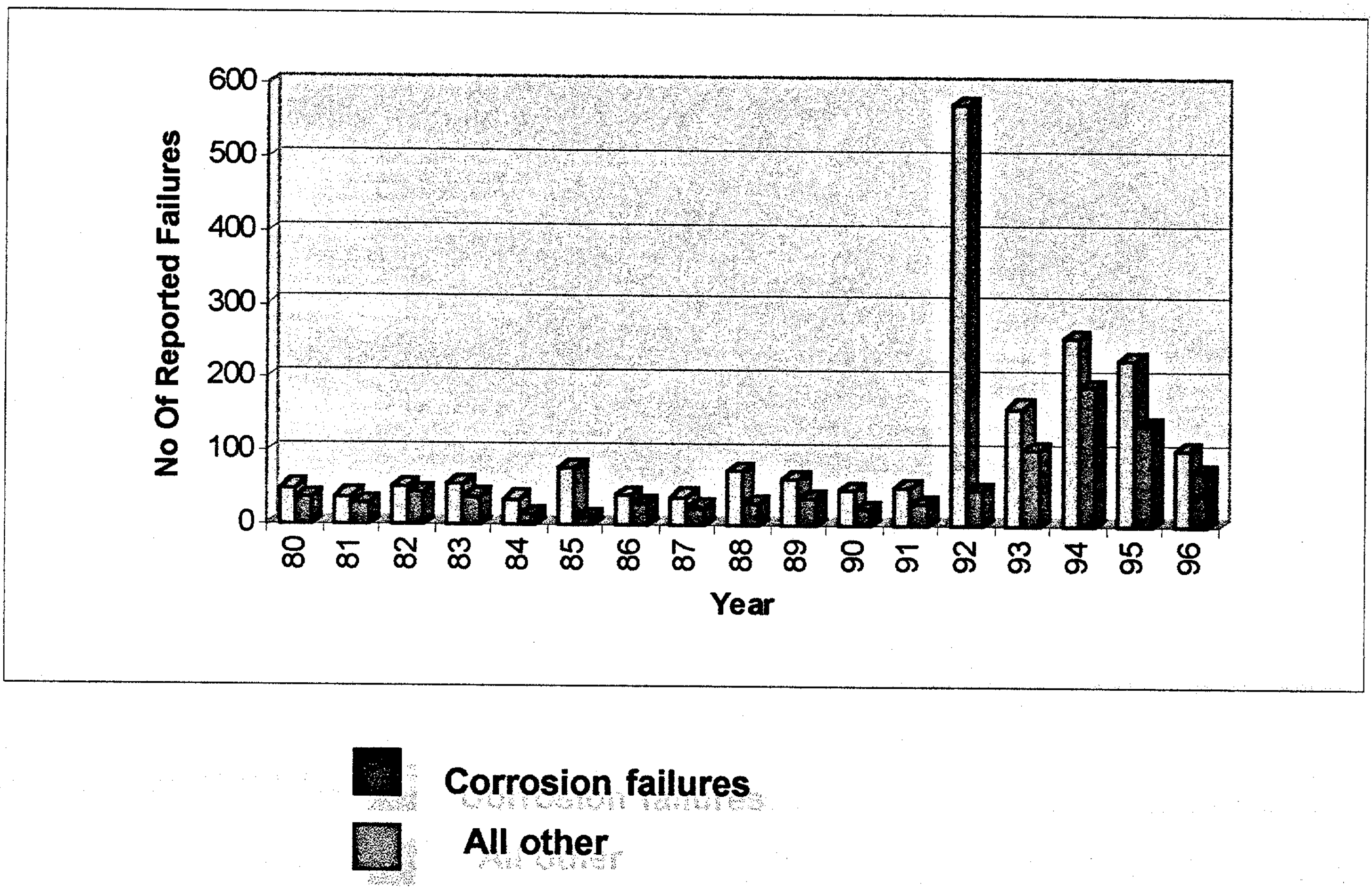


Total No of Internal Corrosion Failures =362
Risers =78 [21%] Submerged Pipe =262 [73 %]
Total Number of External Corroaion Failures = 759
Risers =646 [85%] Submerged Pipe =101 [13.5 %]
Overall Corrosion Failures
Risers =724 [64.5%] Submerged Pipe =363 [32%]

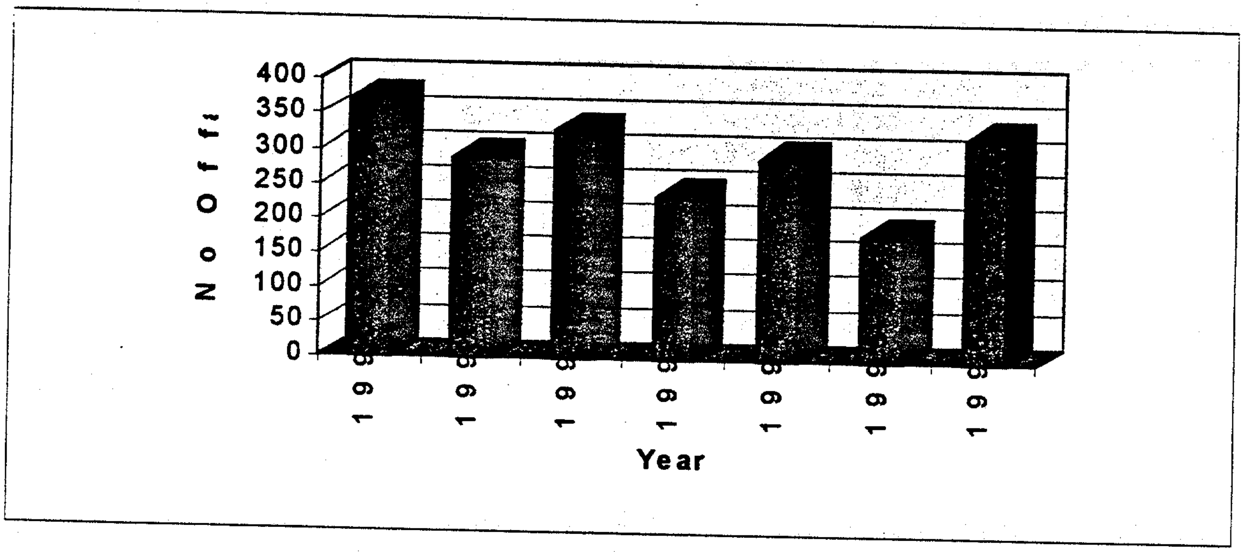
Internal Corrosion Failures
By Product Type
Source: MMS Database 1967-97

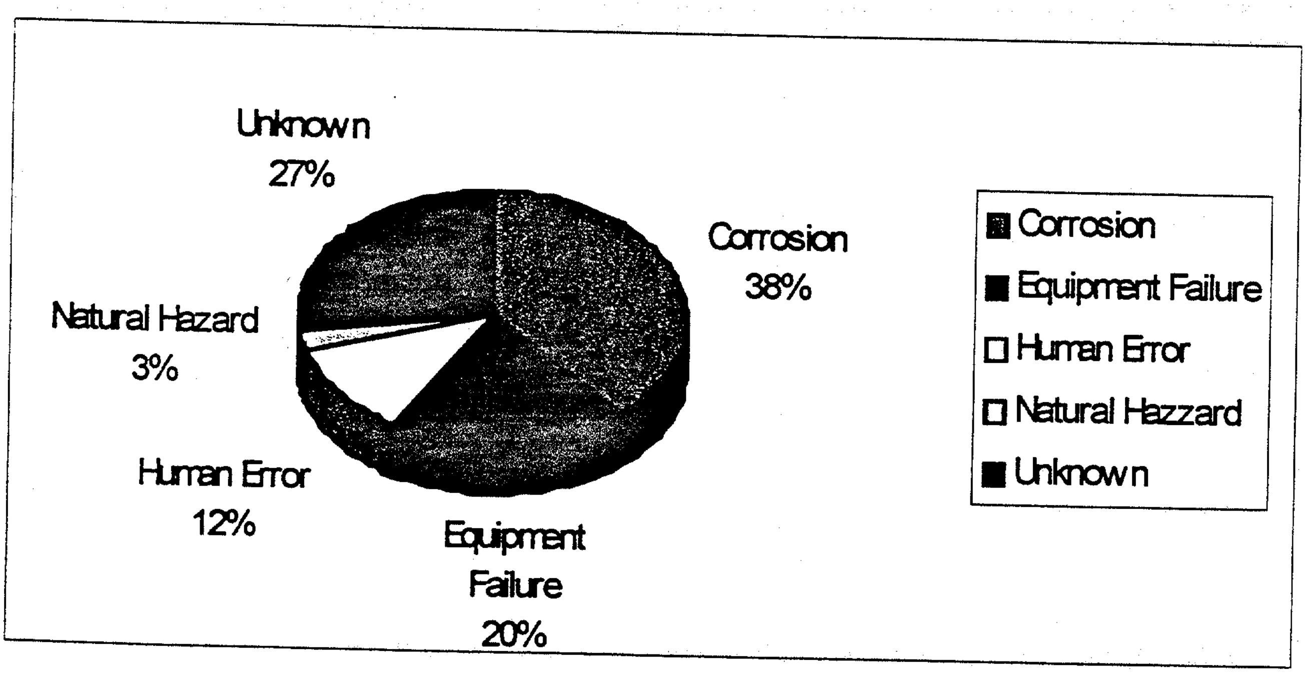


No of Reported Failures per Year
Gulf of Mexico: OCS Region
Source: MMS Database 1967-97

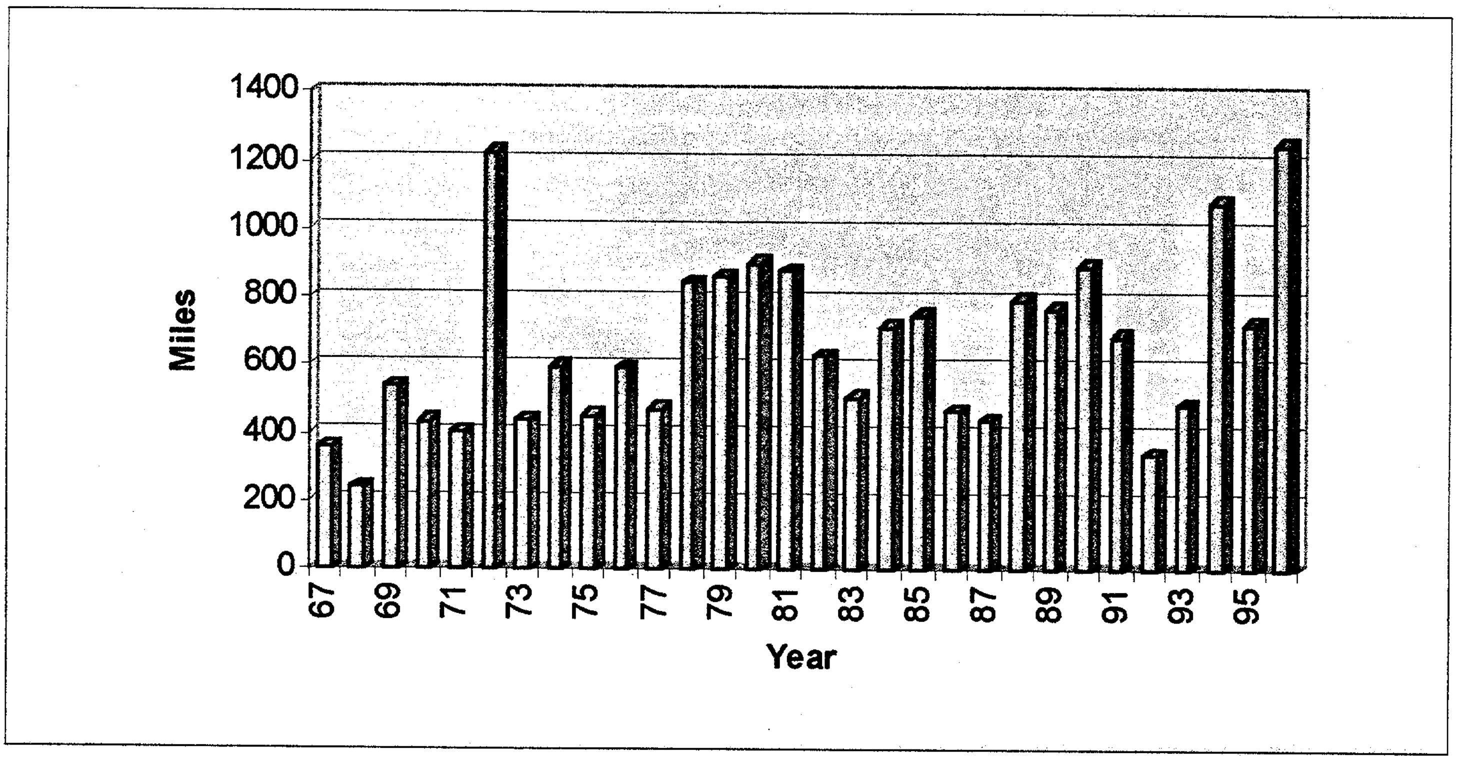


No of Failures per year
Gulf of Mexico: State Waters
Source: CG Database 1990-97

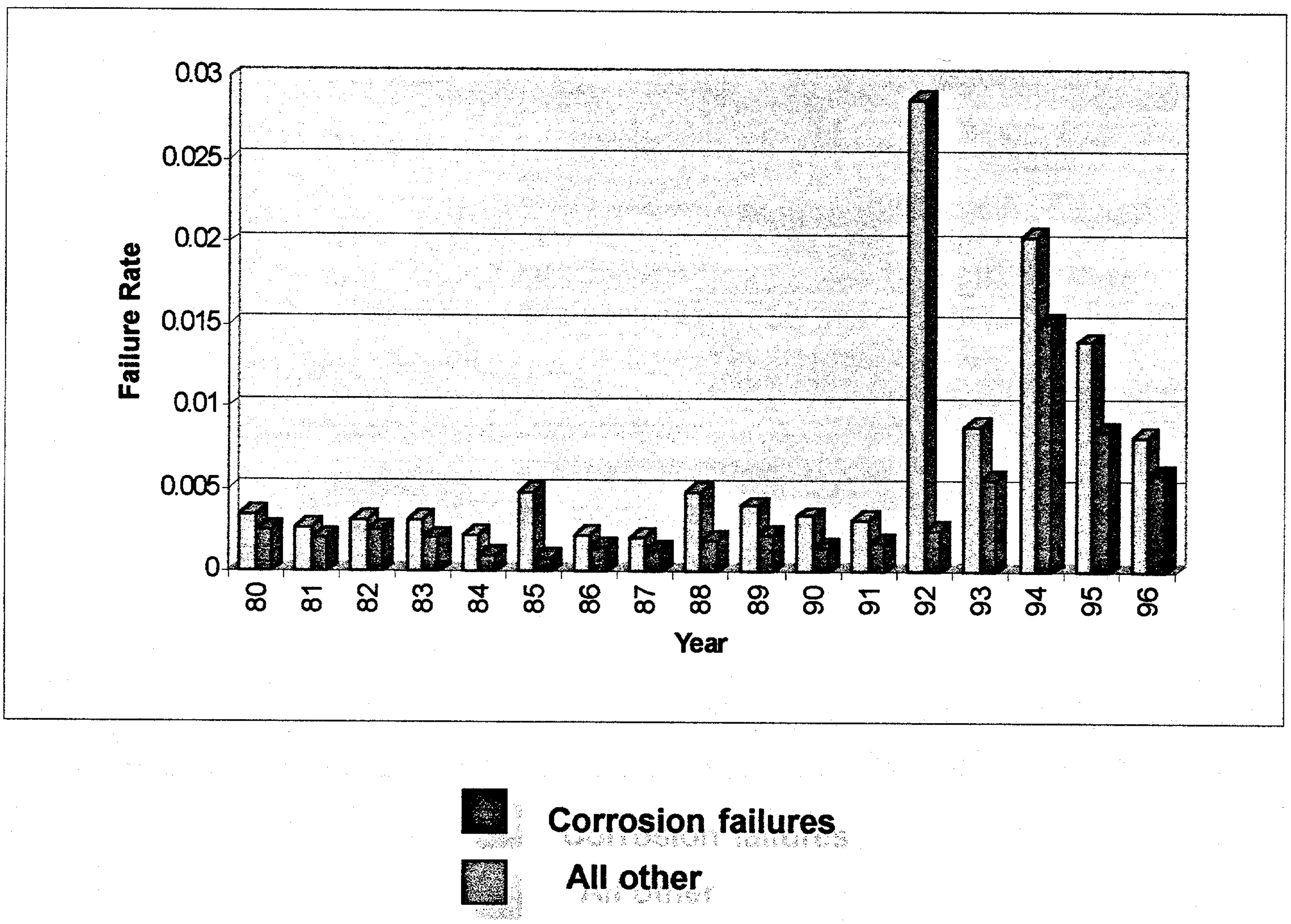




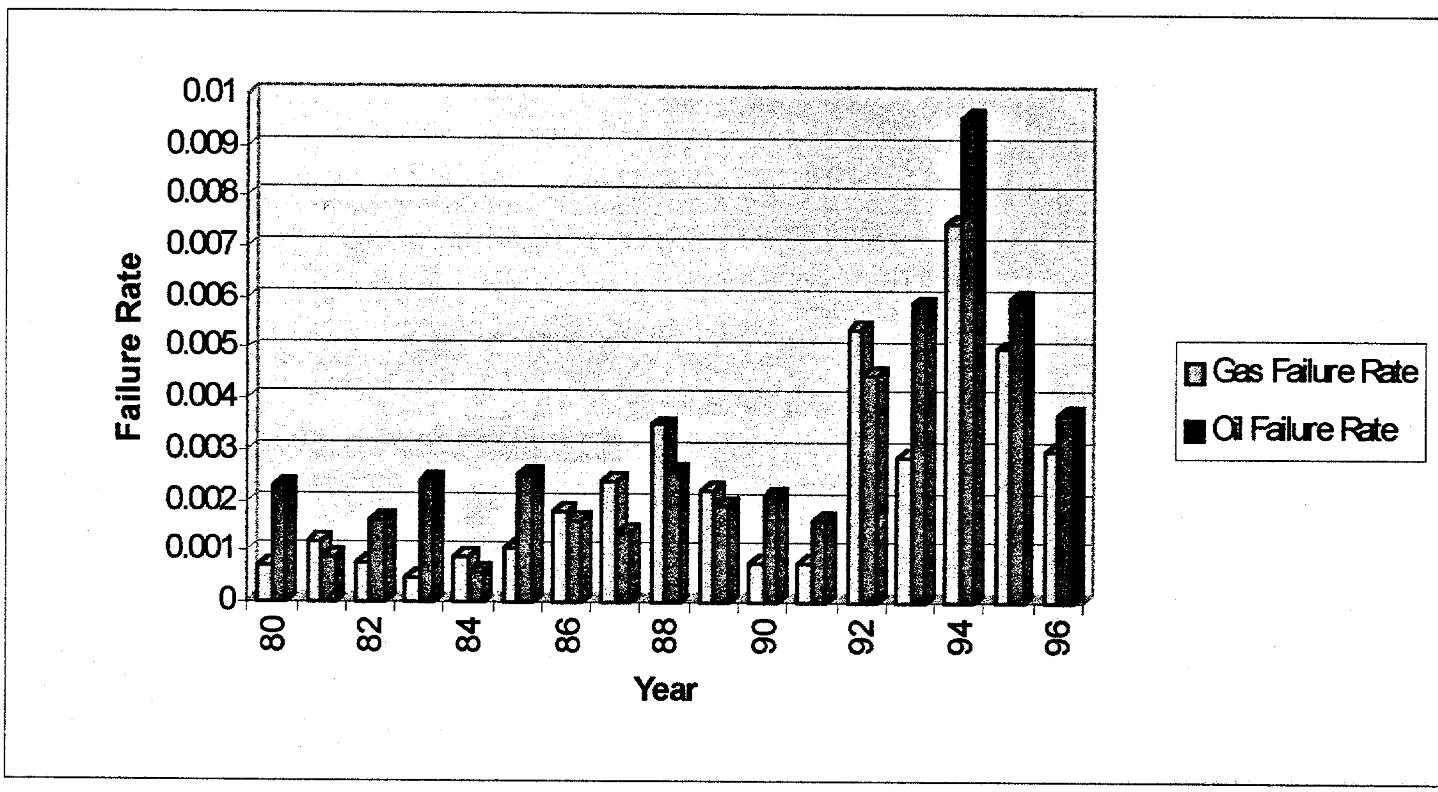
Miles of Pipelines Installed per Year
Gulf of Mexico: OCS Region
Source: MMS Database 1967-97



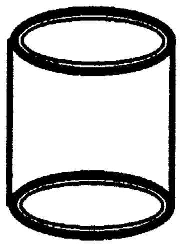
Failure Rate: # Failures/Mile.Year
Gulf of Mexico: OCS Region
Source: MMS Database 1967-97

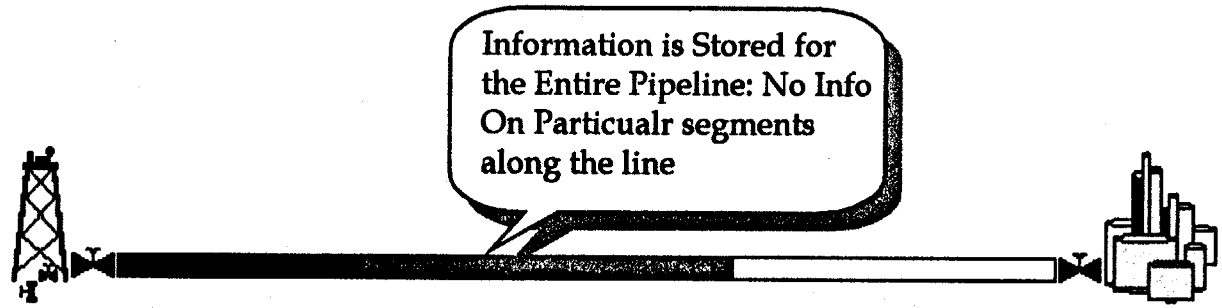


Failure Rate: Oil & Gas Pipelines
Gulf of Mexico: OCS Region
Source: MMS Database 1967-97



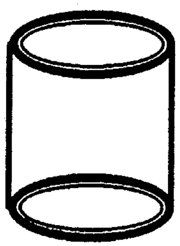
Reliability Database for Offshore Pipeline Failures

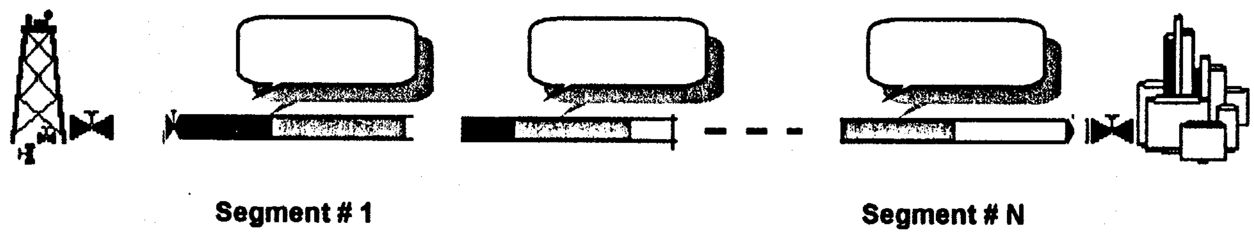




Current: Failure Database

Offshore Pipeline Treated as one Entity

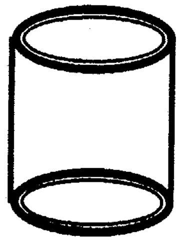


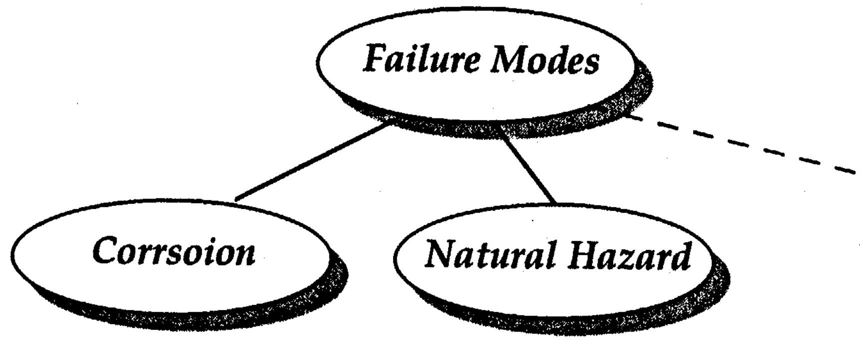


Recommended: Failure Database

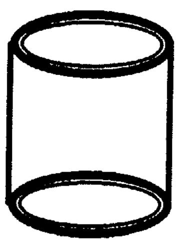
Offshore Pipeline Treated as N Entities: Risk Related Factors are Stored for Every Segment along the Line

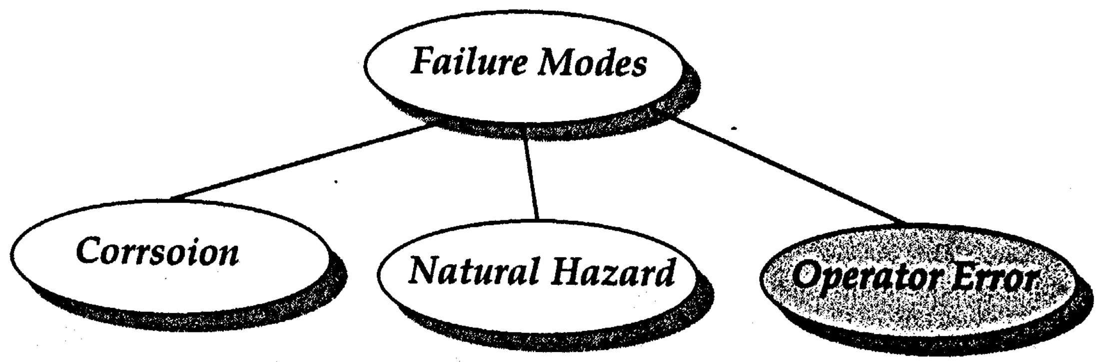
Reliability Database for Offshore Pipeline Failures





Current: Failure Database





Recommended: Failure Database

Analysis of Offshore Pipeline Failure Data (Conclusion)

- An analysis of the 30-year (1967-97) pipeline failure database compiled by the US Minerals Management Service revealed the following:
- Corrosion is the leading cause of failures of subsea pipelines in the US. Gulf of Mexico, (outer continental shelf region and state waters).
- Third-party incidents, storms, and mud slides are additional causes of offshore pipeline failures.
- Among corrosion failures, external corrosion accounts for 68% while internal corrosion accounts for 32%.
- Almost 70% of internal corrosion failures occurred in pipelines carrying gas and or mixtures containing gas.
- The majority of external corrosion failures (82%) occurred on risers in the splash zone.

Analysis of Offshore Pipeline Failure Data (Conclusion)

- The failure frequency of offshore pipelines is a complex affair depending on physical processes, pipe characteristics, inspection and maintenance policies and actions of third parties.
- A great deal of historical data has been collected and a great deal is known about relevant physical processes. However this knowledge is not sufficient to predict failure frequencies under all relevant circumstances.
- This is due to lack of knowledge of physical conditions and processes and lack of data. Hence, predictions of failure frequencies are associated with significant uncertainties and expert judgment must be used.

Analysis of Offshore Pipeline Failure Data (Conclusion)

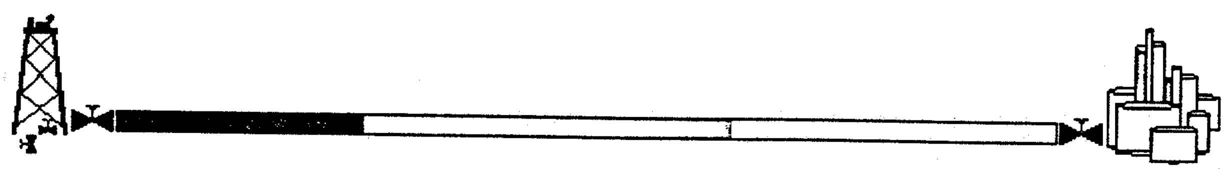
- Are the data available to support risk-based decision making ?

- Considerable data on pipeline incidents is collected each year by operators and reported to MMS. These data applied with care, can provide meaningful insights into the current sources of risk and useful guidance for allocating resources to the most important problems.
- However, the industry failure database needs to be significantly enhanced if the full benefits of risk management are to be realized.
- Of particular importance is enhancing the data that correlates operational and maintenance (O&M) practices to the pipeline failure rates.

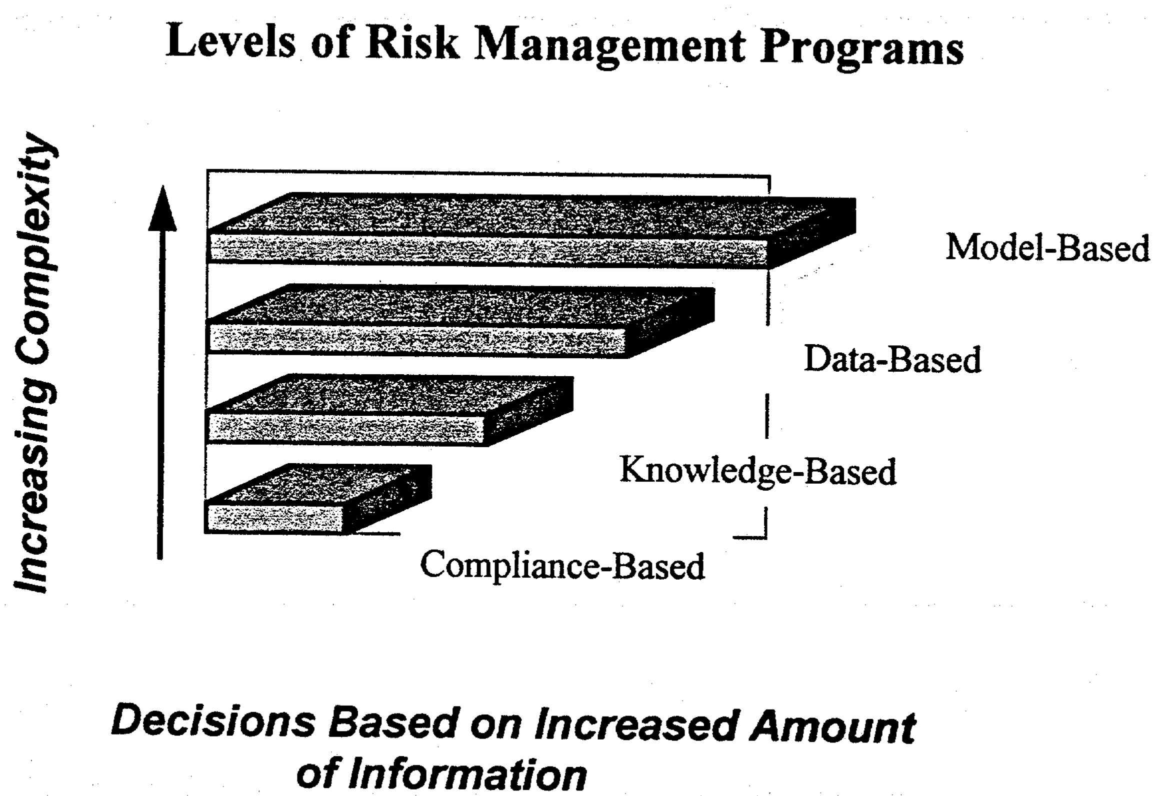
NOTES

Developments in Qualitative Pipeline Risk Assessment

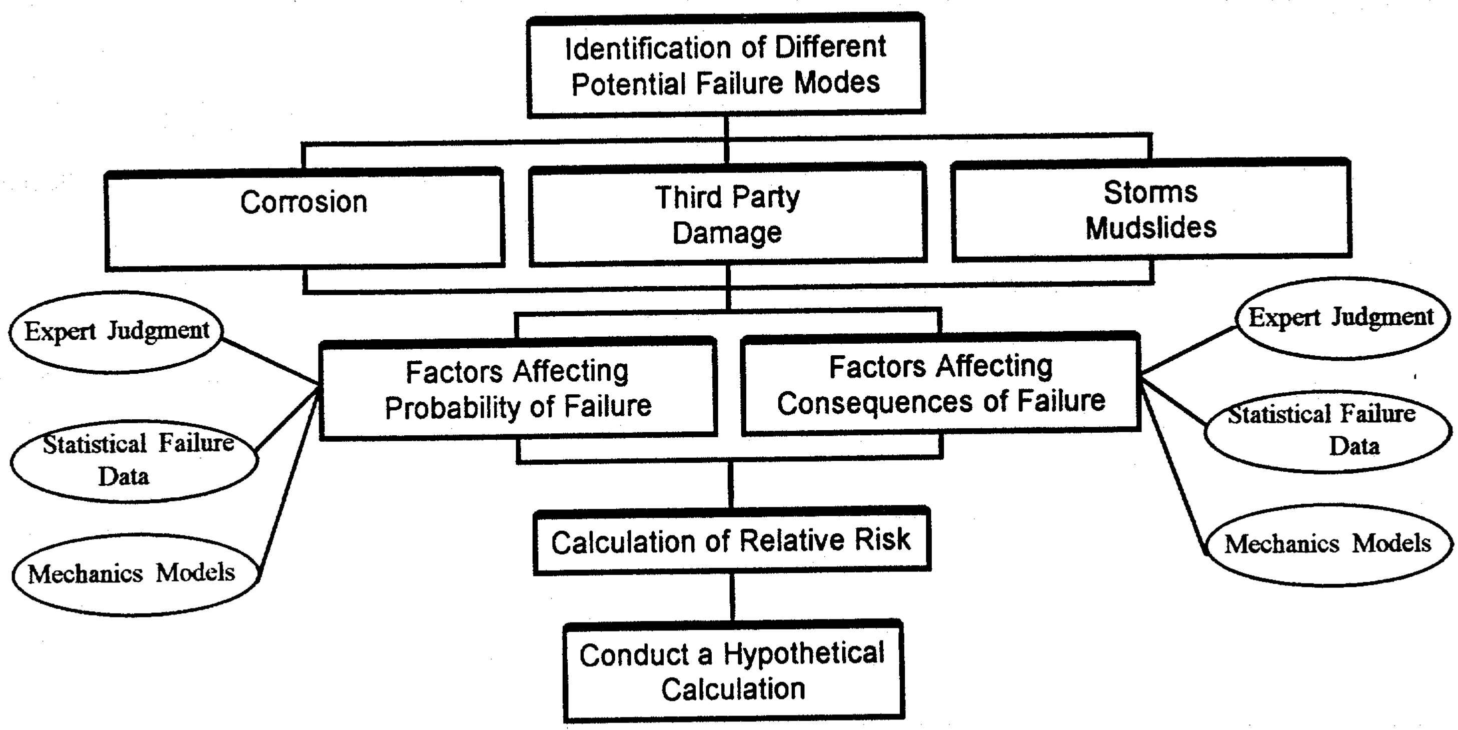
(Non-Piggable Pipes)



Levels of Risk Management Programs



Steps For Developing a Pipeline Risk Ranking Methodology



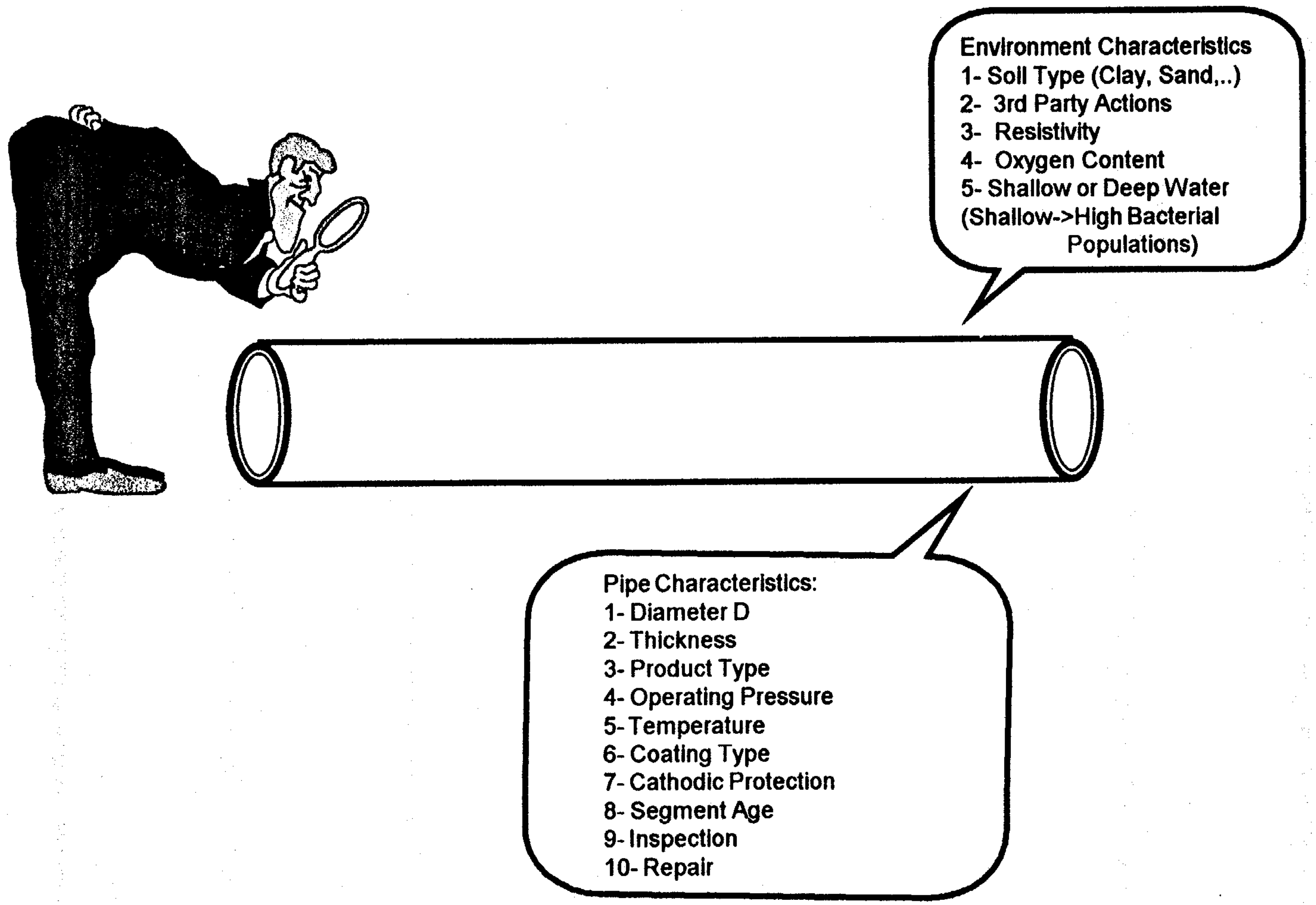
Using Expert Judgment in Risk Analysis

- Probabilistic Risk Assessment can be broken into two parts.

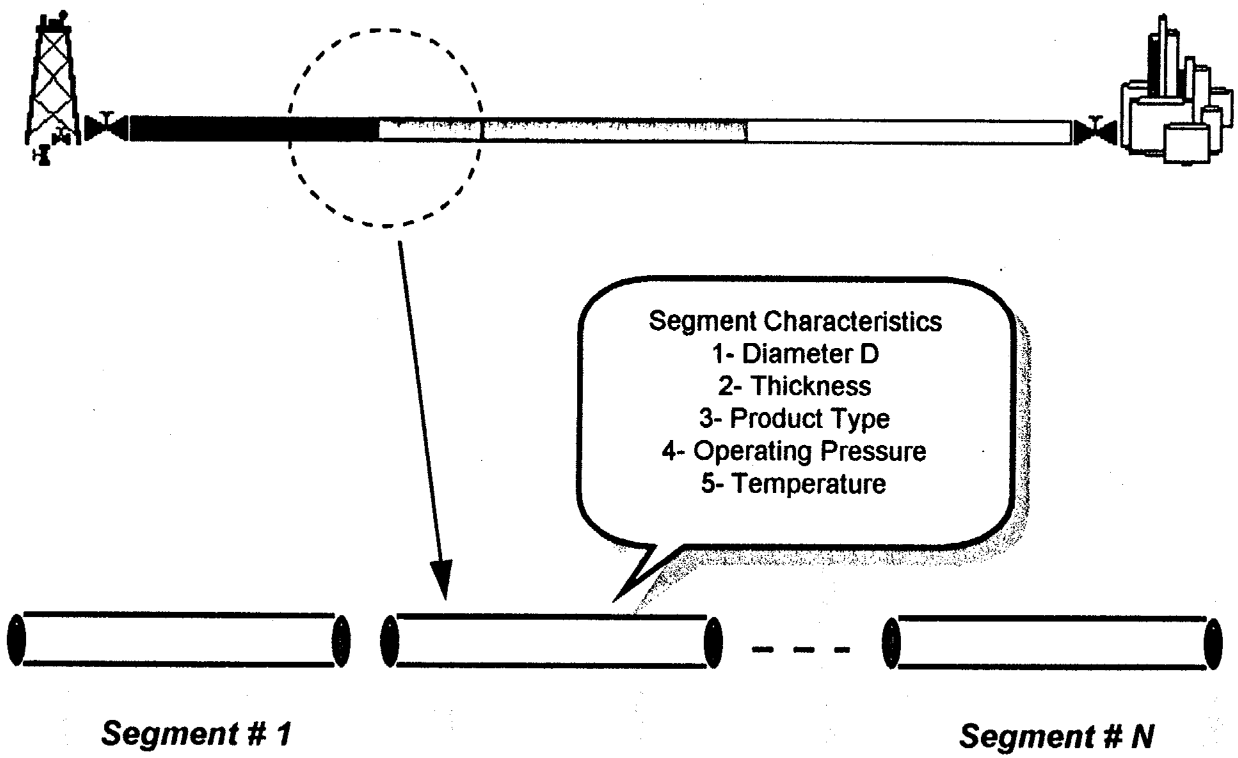
  1) **Accident Prediction** concerns the assessment of the occurrence rates of undesired events. The dominant methodology in this phase is fault tree analysis, and the input data typically concerns occurrence rates of basic events. Beyond the fault tree itself, the physical modeling in this part is generally confined to the determination of life distributions for components.

  2) **Accident Consequence Assessment** concerns the consequences of an undesired event for men and the milieu. The type of data required for consequence assessment is more varied than for accident prediction, and there is no dominant methodology.

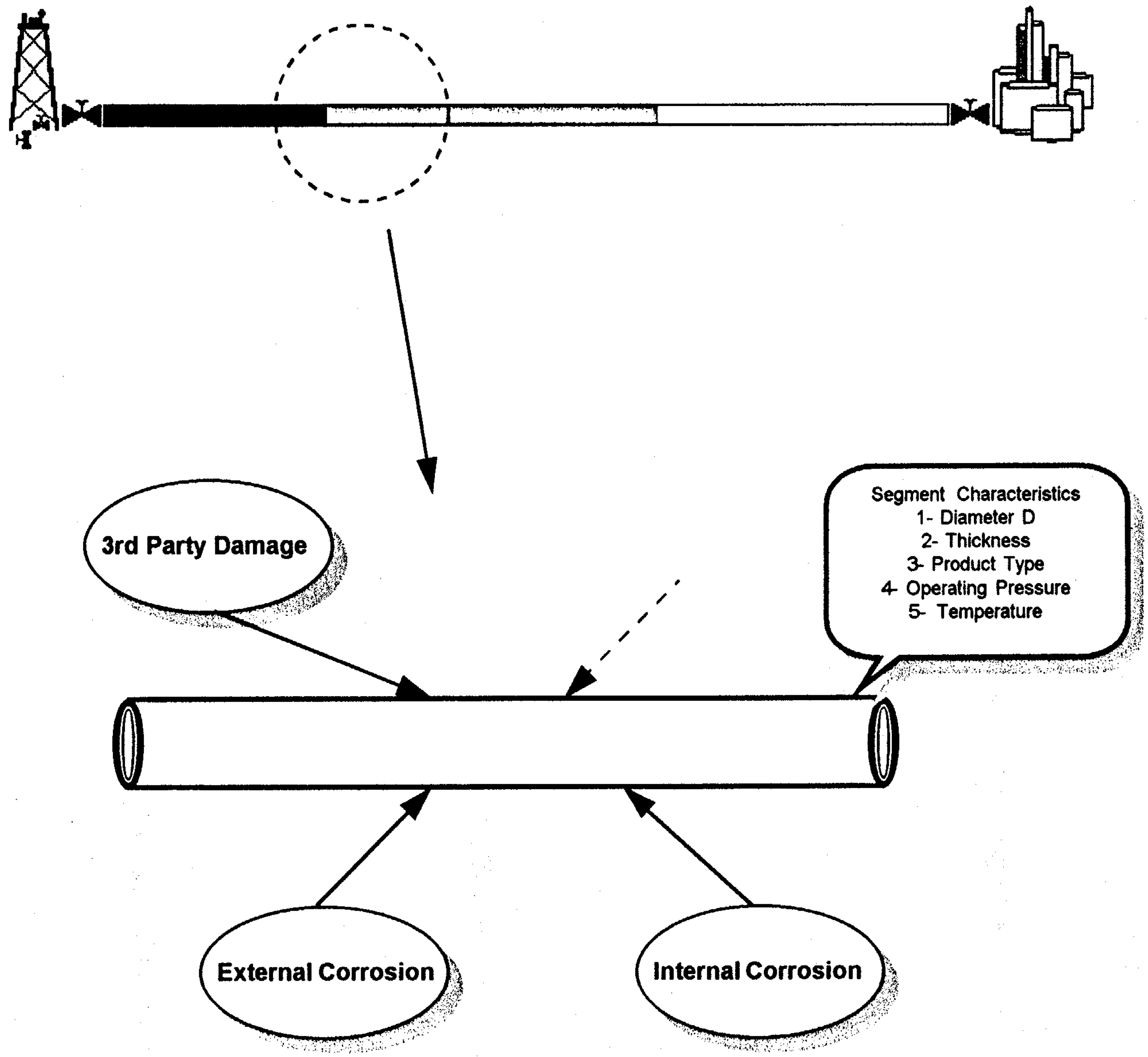
Using Expert Judgment in Risk Analysis



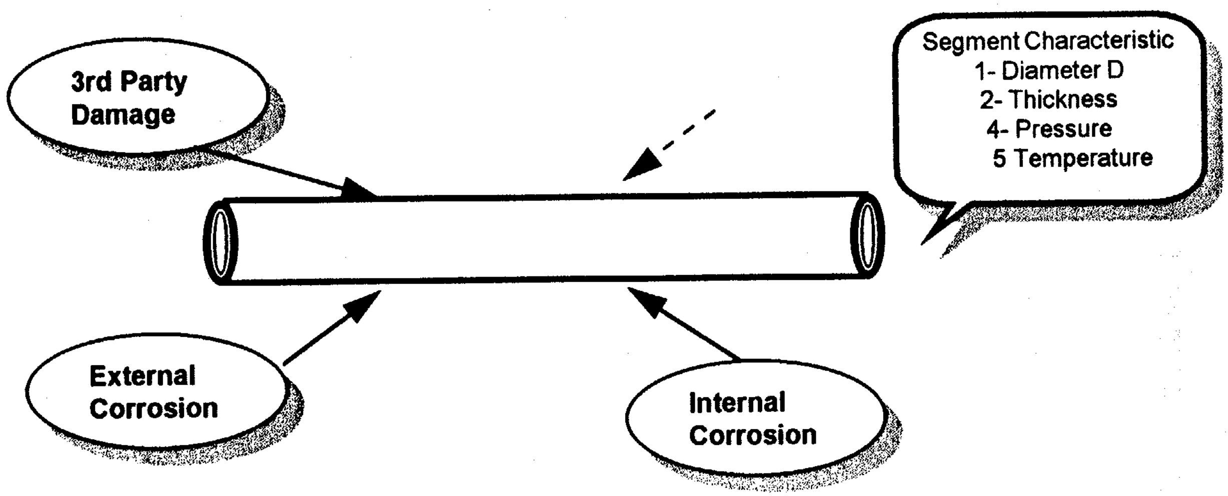
An Offshore Pipeline is a Series System Made of N segments. Different Segments may Have Different Characteristics.



Segment of an Offshore Pipeline Subjected to Multiple Failure Modes



Failure Probability: 1 Segment Subjected to Multiple Failure Modes



F_1= Failure Due to 3rd Party Damage
F_2= Failure Due to Internal Corrosion
F_3= Failure Due to External Corrosion
F_4= Failure Due to Natural Hazard (Storms)

The probability of failure for the segment is:

$P_{Failure}=P(F_1 \cup F_2 \cup F_3 \cup F_4)$

$P_{Failure}=P(F_1)+ P(F_2)+ P(F_3)+ P(F_4)-P(F_1 \cap F_2) -P(F_2 \cap F_3)-...........+P(F_1 \cap F_2 \cap F_3 \cap F_4)+...$

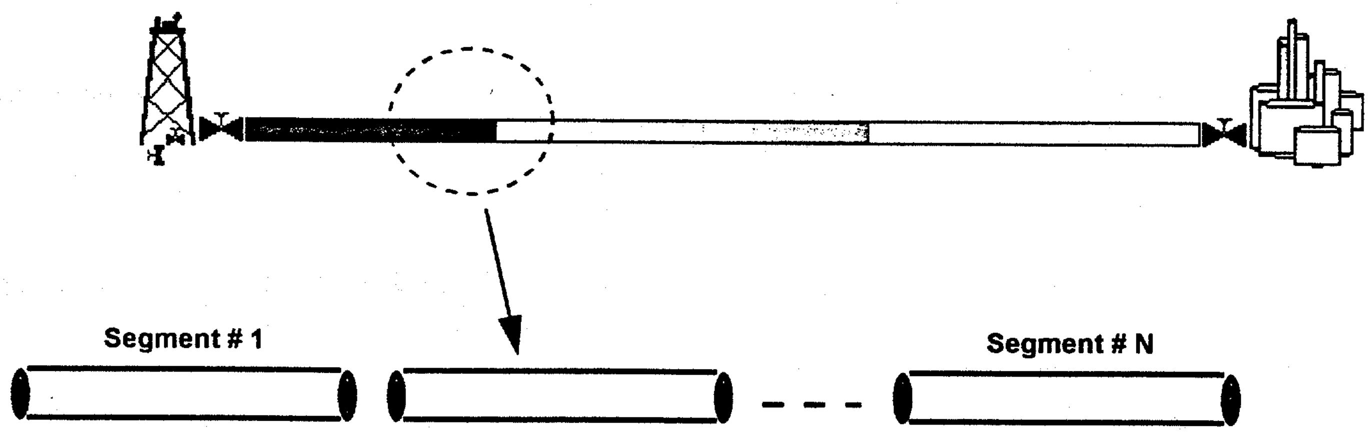
with the assumption of independence and $P(F_i) << 1$
implies that terms like $P(F_i \cap F_j)=P(F_i)P(F_j) \approx 0$ and therefore

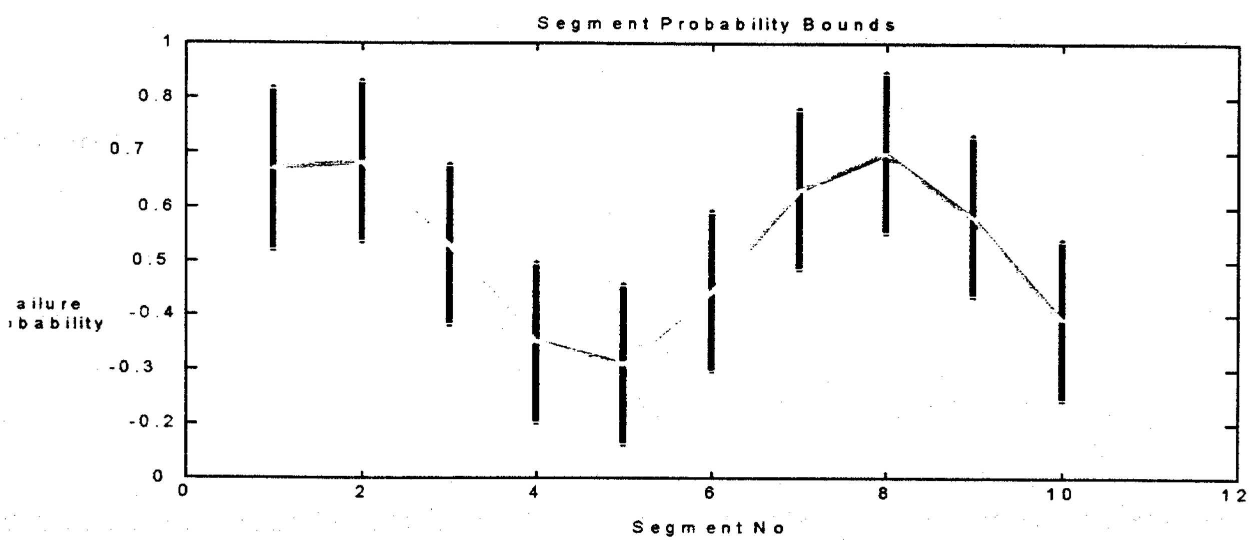
$$P_{failure} \approx P(F_1)+ P(F_2)+ P(F_3)+ P(F_4) \qquad \text{.....(1)}$$

$$P\{j\}_{Failure} \approx \sum_{i=1}^{k} P(F_i) \qquad \text{.....(2)}$$

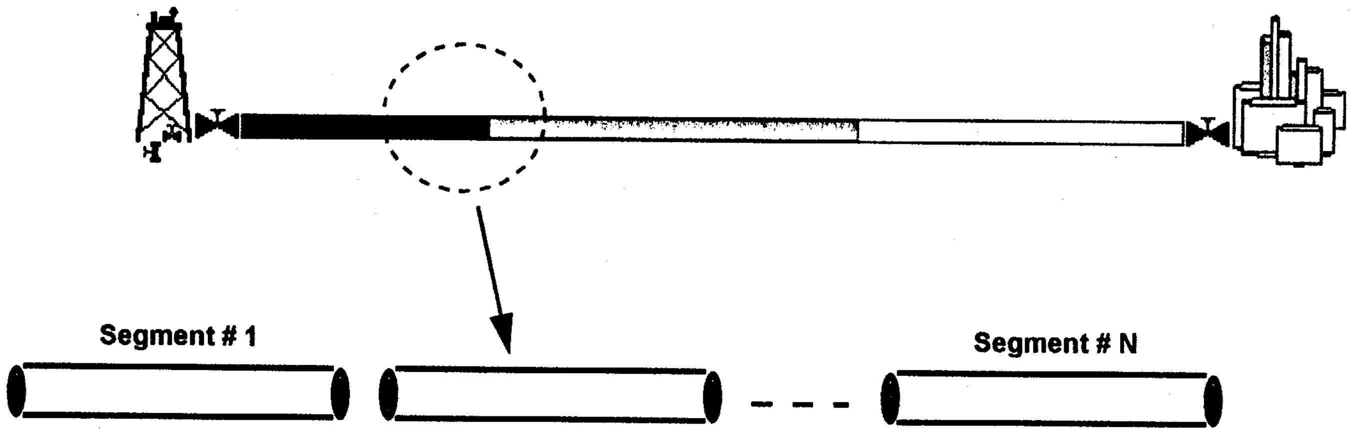
where {j} is an index representing the jth segment and k is the number of potential failure modes

Upper & Lower Bounds For The "Segment" Probability of Failure Same Bounds Exist For Segments Along The Line





Failure Probability :Offshore Pipeline: Series System Made of N segments. Different Segments may Have Different "failure probabilities".



F_1= Failure of 1st Segment
F_2= Failure of 2nd Segment
F_3= Failure of .... Segment
F_4= Failure of the Nth Segment.

*The **probability of failure for the Entire Pipeline*** is:

$P_{Failure}=P(F_1 \cup F_2 \cup F_3 \ldots\ldots \cup F_N)$

$P_{Failure}=P(F_1)+P(F_2)+P(F_3)+P(F_4)+\ldots\ldots-P(F_1 \cap F_2)-P(F_2 \cap F_3)-\ldots\ldots+P(F_1 \cap F_2 \cap F_3 \cap F_4)+\ldots$

Again with the assumption of independence and $P(F_i) << 1$
implies that terms like $P(F_i \cap F_j)=P(F_i)P(F_j) \approx 0$ and therefore

$$P_{failure} \approx P(F_1)+P(F_2)+P(F_3)+\ldots\ldots+P(F_N) \qquad \ldots\ldots \qquad (3)$$

$$P_{Failure} \approx \sum_{j=1}^{N} P(F_j)$$

where {j} is an index representing the jth segment.
Using equation (1) for the segment probability of failure, *An upper bound for the **probability of failure for the Entire Pipeline*** is:

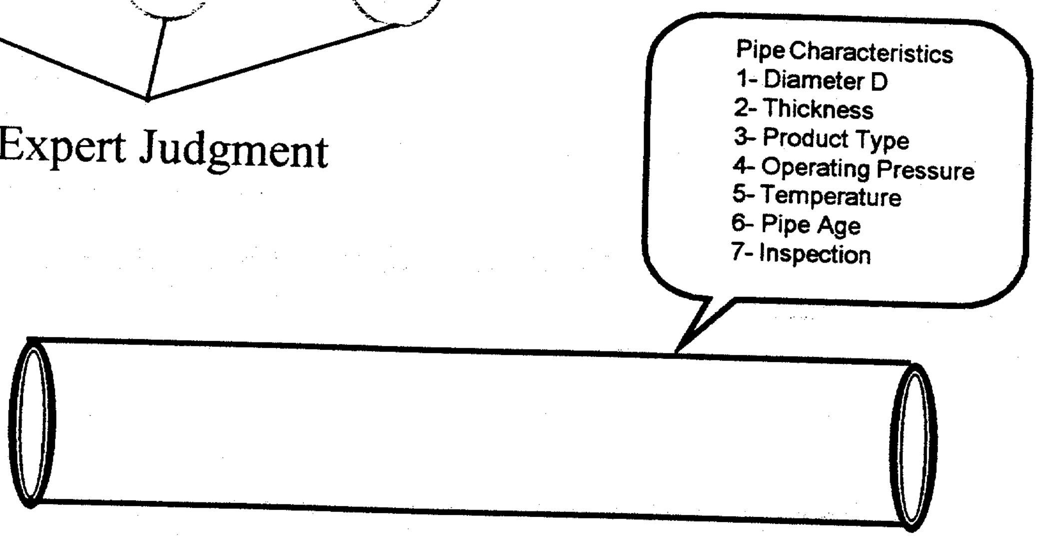
$$P_{Failure} \approx \sum_{j=1}^{N} \sum_{i=1}^{k} P_{\{j\}}(F_i)$$

Example Application: Kiefner et al., Muhlbauer Qualitative Assessment of Failure Probability

$$P_{failure} = \sum_{i=1}^{n} Wi * Xi$$

$$P_{failure} = 0.60 * I_{External} + 0.20 * I_{Buried} + 0.20 * I_{Atmospheric}$$

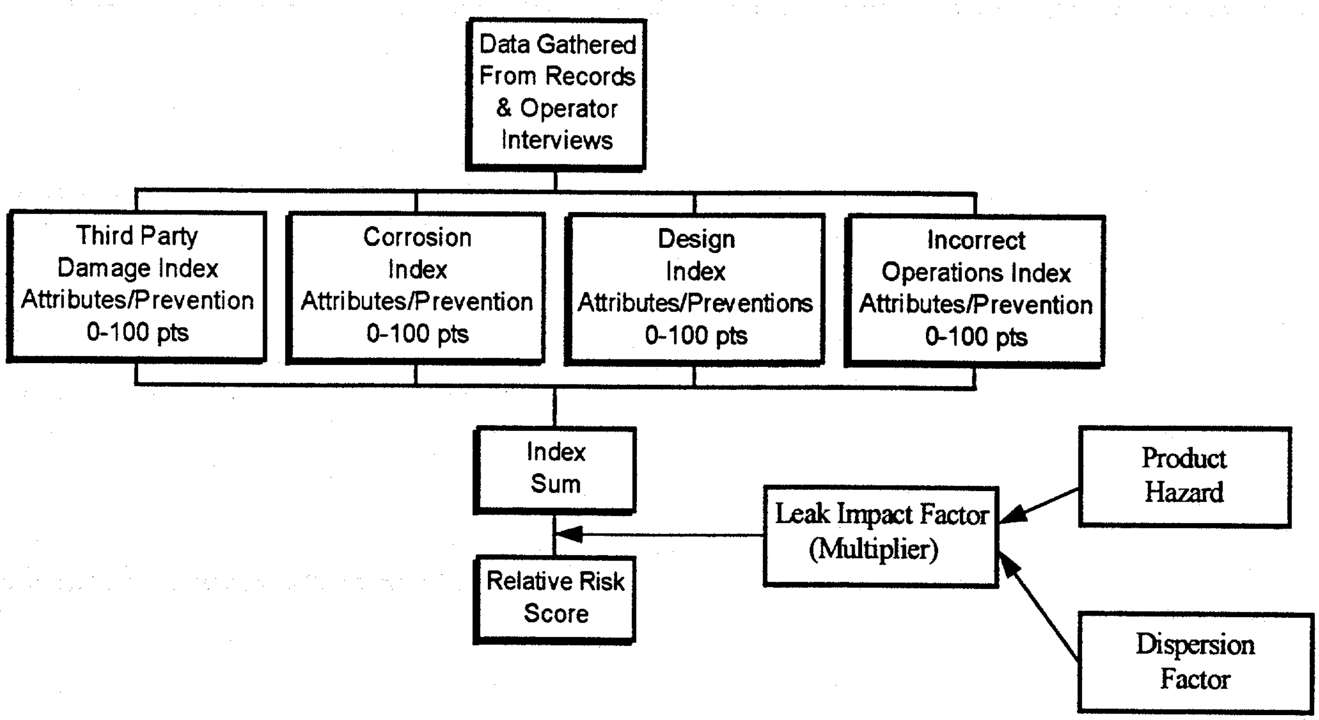
Expert Judgment



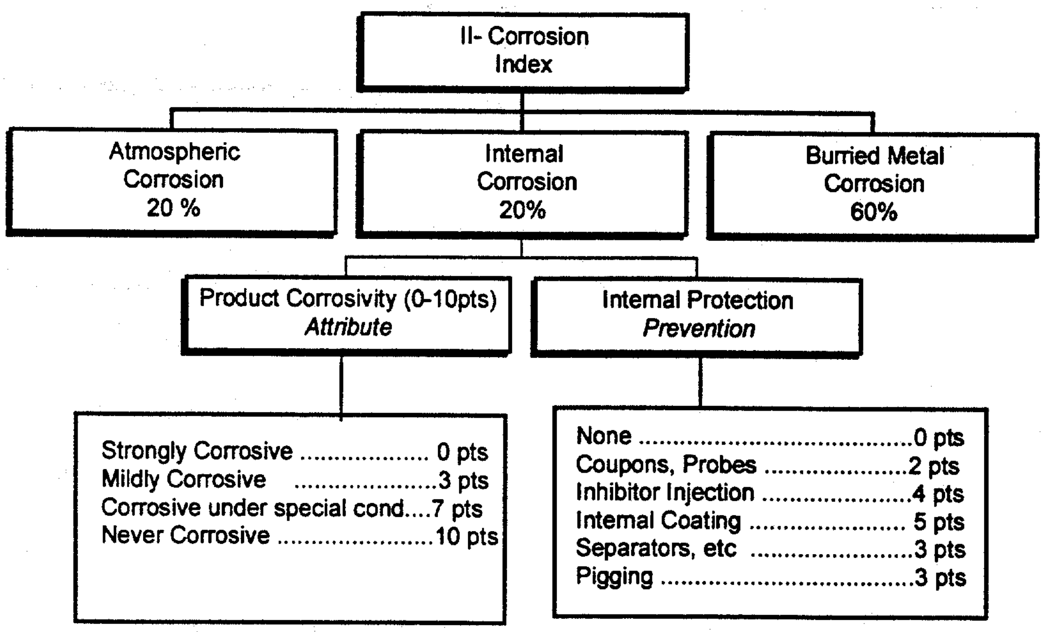
Factors that affect the Probability of Failure [Xi]
Weighting Factors [Ai](Based on Expert Judgment)
Provide Relative Ranking (Score) Between Segments

Examples: Scoring Methods (Muhlubauer, 1992)

[Pipeline Risk Controller]

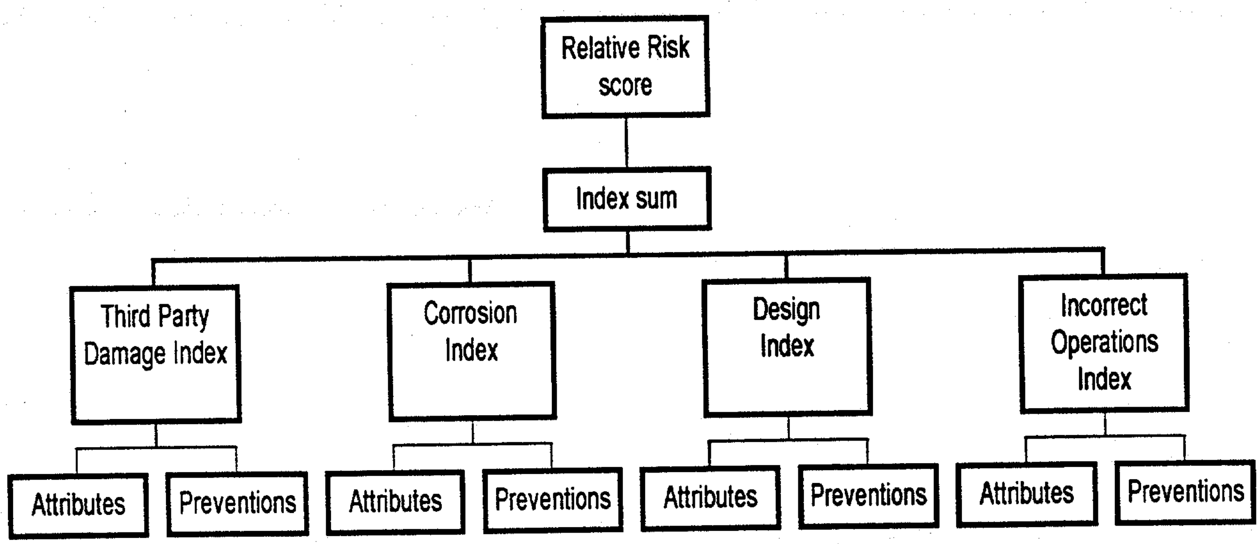


Corrosion Index
Source: Muhlbauer, Pipeline Risk Management Manual

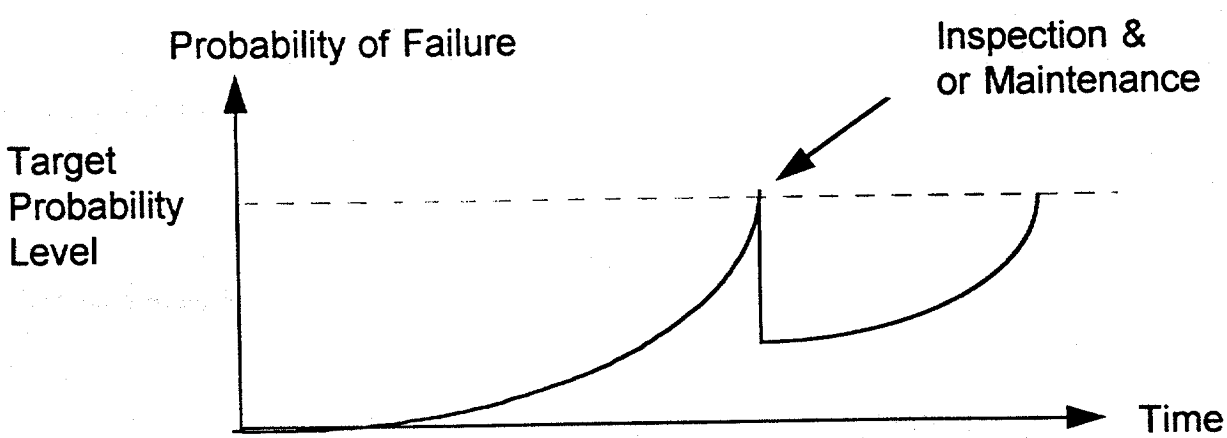


Effect of Inspection & Maintenance Activities on The Probability of Failure

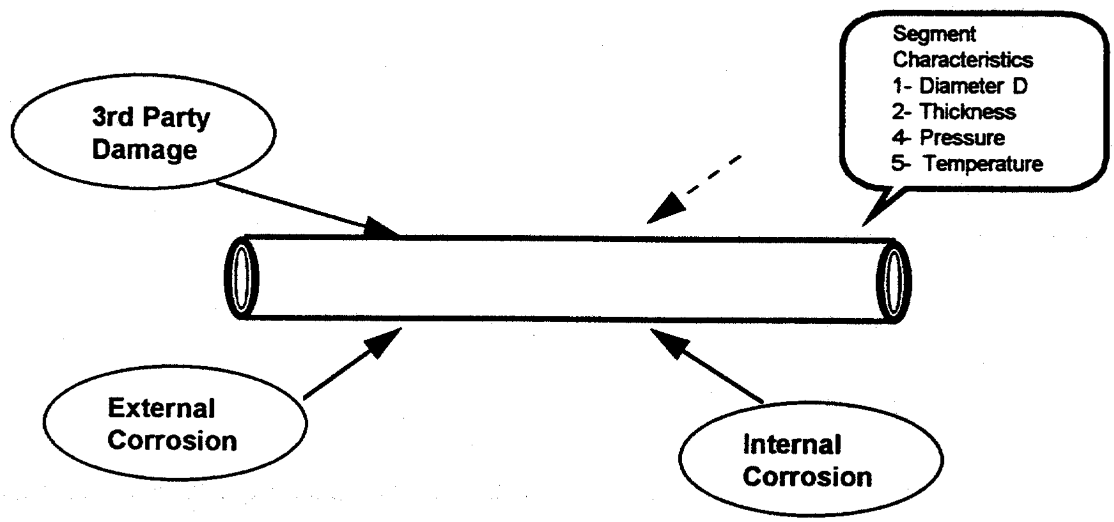
Qualitative



Quantitative



Failure & Survival Probabilities
Segment: Multiple Failure Modes



F_1= Failure Due to 3rd Party Damage
F_2= Failure Due to Internal Corrosion
F_3= Failure Due to External Corrosion
F_4= Failure Due to Natural Hazard (Storms)

The probability of failure for the segment is:

$P_{Failure} = P(F_1 \text{ or } F_2 \text{ or } F_3 \text{ or } F_4)$

$P_{Failure} = P(F_1) + P(F_2) + P(F_3) + P(F_4) - P(F_1 \cap F_2) - P(F_2 \cap F_3) - \ldots\ldots\ldots\ldots + P(F_1 \cap F_2 \cap F_3 \cap F_4) + \ldots$

$P_{failure} \approx P(F_1) + P(F_2) + P(F_3) + P(F_4)$

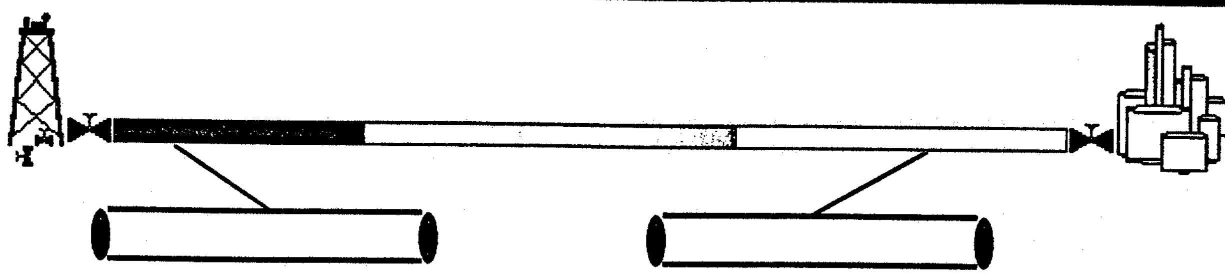
The probability of Survival for the segment is:

$P_{Survival} = P(F_1 \text{ and } F_2 \text{ and } F_3 \text{ and } F_4)$

$P_{Survival} = P(F_1)\, P(F_2)\, P(F_3)\, P(F_4)$

Indices Should Be Added if They Represent Failure
& Multiplied If They Represent Survival (Safety)
Cannot average the indices over the segments if they represent Safety

Proper Assignment of Failure Indices



	3rd Party Index	Corrosion Index	Design Index	Operations Index	Risk Score	
					Adding	Multiplying
Segment 1	99	3	99	99	300	2M
Segment 2	75	75	75	75	300	31M

In Both Segments, sum of the indices is 300. Relative risk score is the same for both segments. Segment 1 will almost certainly fail since the corroison index 3, while segment 2 is relatively safe since all indices are 75.

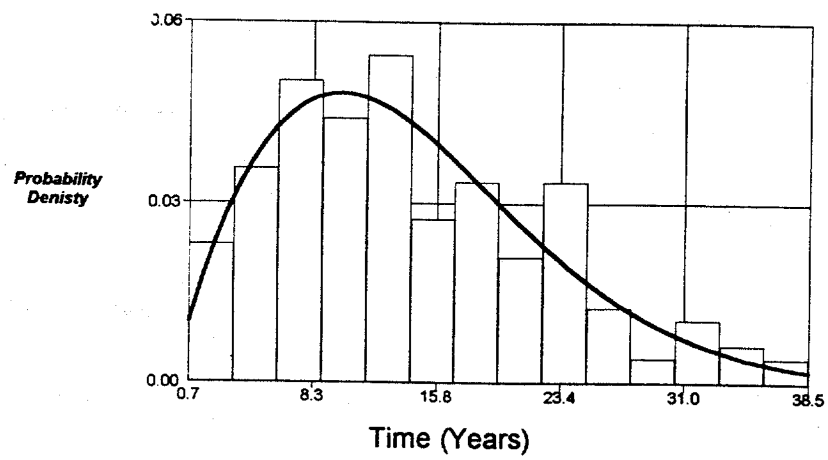
	3rd Party Index	Corrosion Index	Design Index	Operations Index	Risk Score
					Multiplying
Segment 1	0.99	0.03	0.99	0.99	0.029
Segment 2	0.75	0.75	0.75	0.75	0.316

Problem arises because the indices are analogous to P(No Failure) ,Survival, rather than P(Failure) and are Incorrectly manipulated.

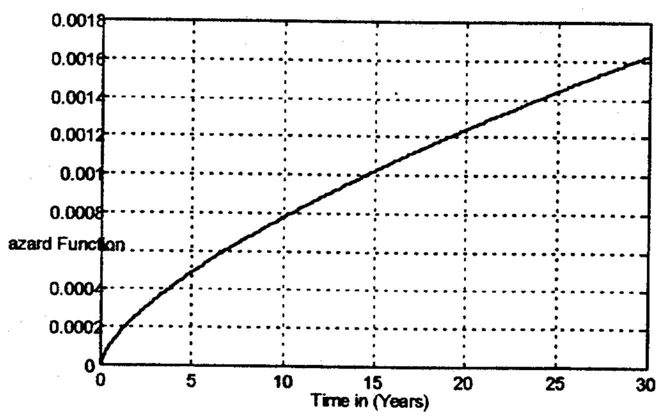
Modeling Lifetime Data of Offshore Pipelines: Weibull Analysis

- There are two basic kinds of failure
  1) Wear-out
  2) Overstress
- Wearout implies that a pipeline segment becomes unusable through long or heavy use. It implies the using up or gradual consuming of material
- Overstress, on the other hand, refers to the event that an applied stress exceeds the strength of the material.
- Weibull analysis is one of the most widely used probability distribution in engineering reliability. The distribution is often used in analyzing lifetime data.

Distribution of Time to Failure, Life Length, Due To Internal Corrosion For Gas Pipelines, D>16 in

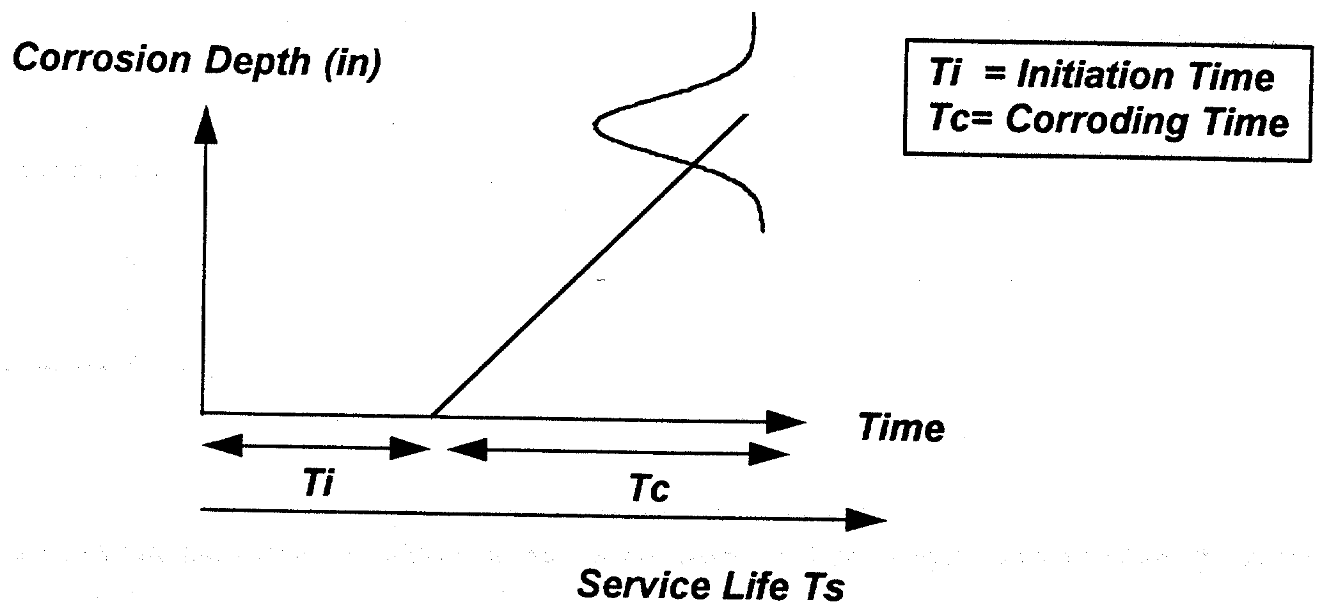


Distribution of Time to Failure, Life length ,Due to Internal corrosion For Gas Pipelines D>16 in: Weibull Distribution with Parameters Shape Parameter α=1.76 Scale Paramter β =16.05 Years



Hazard function (Conditional Probability of Failure) Based on the Weibull Distribution

Probabilistic Corrosion Modeling



Modeling Corrosion Initiation and Penetration

Corrosion Models (Sweet Corrosion CO_2)

- Shell 75, 91, 93, 95 (de Waard)
- Cormed (Elf)
- Lipucor (Total)
- KSC V (IFE)
- SSH model (Statoil, Saga, Hydro)
- USL, Univeristy of Southern Louisianna
- ASSCA (Alloy Selection System for Carbonic Acid)

No Predictive Model For Sour Corrosion

Corrosion Rate: dW&M Shell95

- The dW&M model works for multiphase oil, condensate and gas pipelines.

$$CR = 10^{5.8 - \frac{1710}{T} + 0.67 \log(f_{CO_2})} . xm.i.F_{Scale}.F_{pH}$$

where: T = Temperature (^{o}K)

f_{CO_2} = Fugacity of CO_2

Total Pressure.mole fraction. CO_2 fugacity coeff

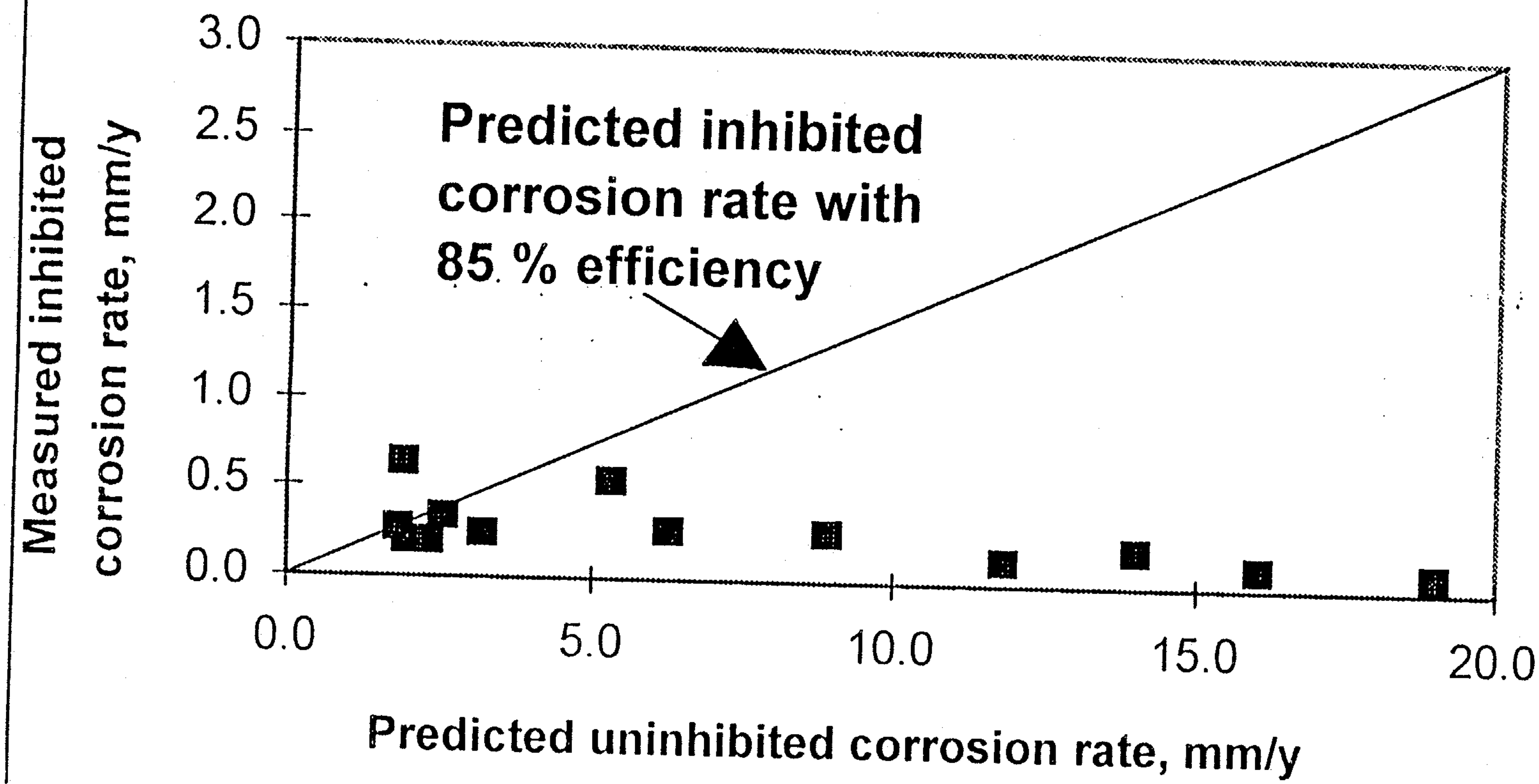
x_m= Corrosion Rate Uncertainty Factor (Shell 95)

F_{Scale} = Correction factor for scale formation

F_{pH} = Correction factor for pH

i = Inhibitor Efficiency

Field comparison inhibited wet gas pipelines



Corrosion Rate Determining Parameters

- Temperature
- Water Composition

  -CO_2 H_2S,pH, acetic acid, salts, corrosion products

  - Operational parameters

  flow rate, flow regime, water wetting
- Steel Properties

  -Micro structure, alloying elements, consumables
- Prehistory

Corrosion Rate Determining Parameters

- Corrosion will only start when enough water is present in the production and the flow rate of the product is low enough for water to form persistent layers. Once corrosion has started, the water tends to persist in the corrosion pits and continues.
- Usual guesstimates of when water layers will form are :

  - If water cut is above 20% or

  -if superficial flow rate is below 3 ft/sec

Reliability Approach: Limit State Non-Piggable Pipes

- Limit State Function:
- Failure Occurs when g<0;

  $g=d-CR.Tc$

  d= Maximum allowable corrosion depth

  CR= Corrosion rate

  Tc=Corroding time

Inhibitor Effects: Relative Operating Parameters

- Inhibitor Efficiency (Deterministic Value 85%) can be categorized as:
- Very High Level of Committment To Operation
- High Level of Committment To Operation
- Low Level of Committment To Operation
- No Inhibition

Summary & Conclusions

- An approach has been developed for the reliability assessment of non-piggable pipes. The approach has its roots in reliability based design
- Uncertainties in CO_2 corrosion rate are addressed
- Actual strength of a locally corroded pipe is accounted for.
- Effects of operating history is addressed.
- Calibration and verification of the approach using actual case studies

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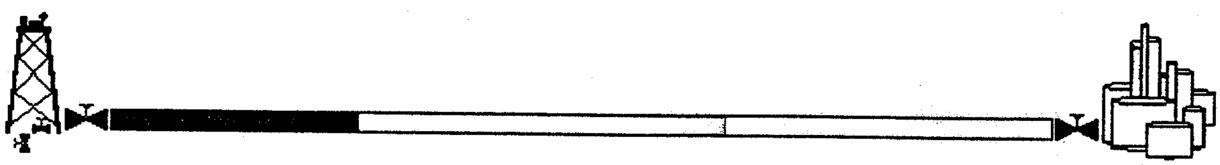
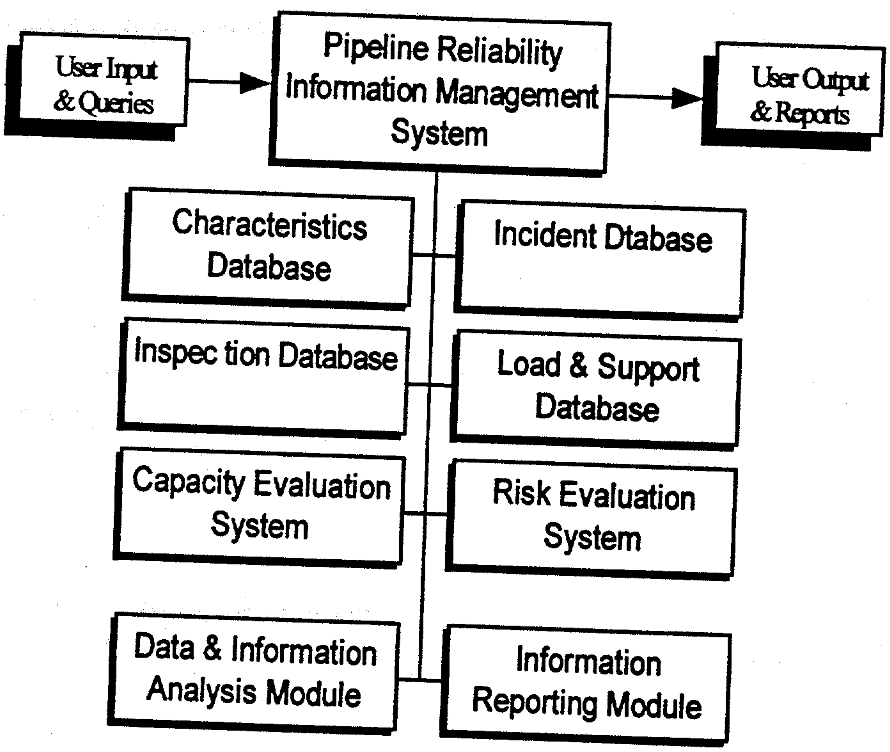
Developments in Quantitative Pipeline Risk Assessment

(Piggable Pipes)



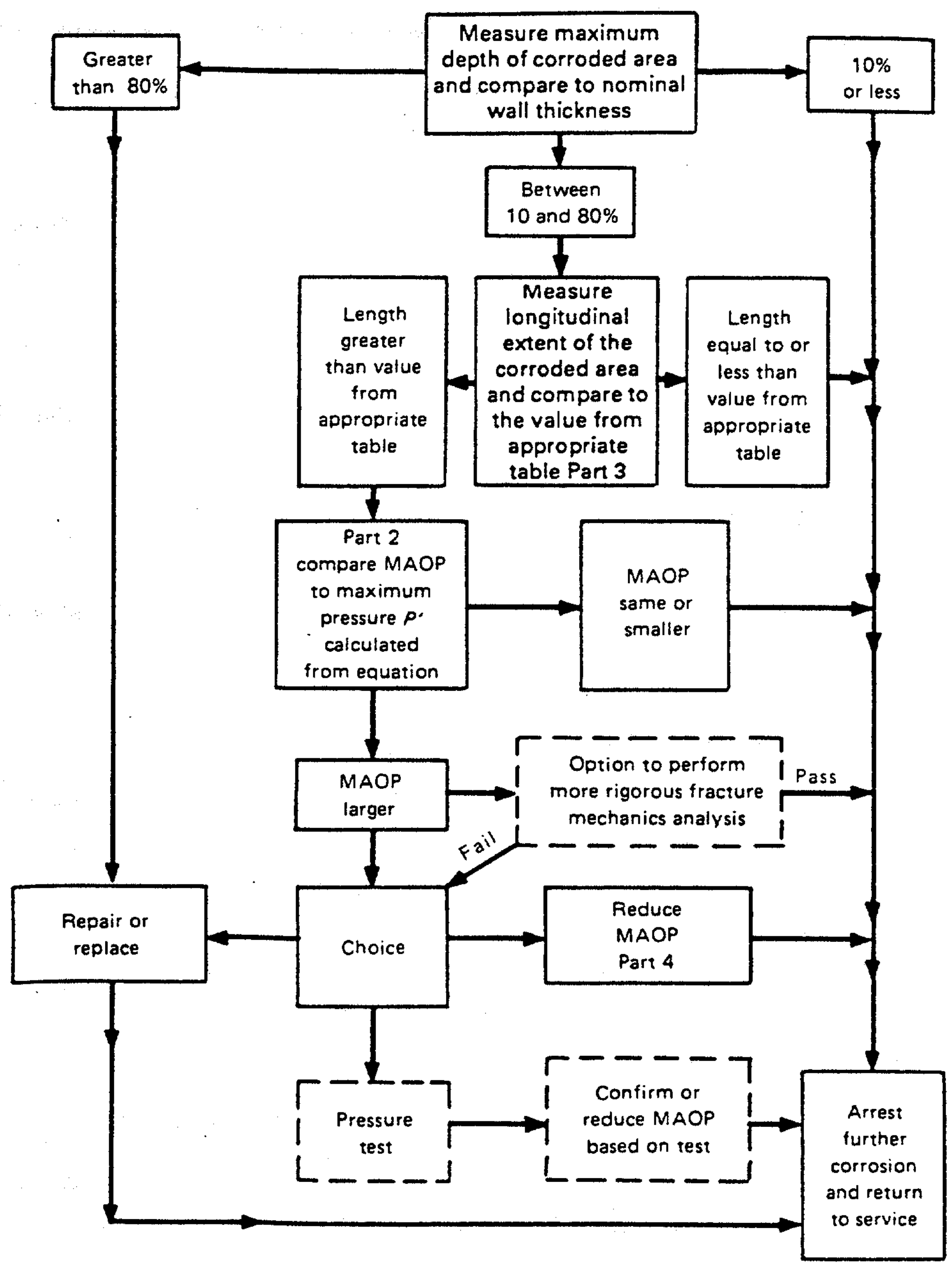
Structure of Pipeline Inspection, Maintenance, and Performance Information System (PIMPIS)



Existing Residual Strength Criteria

- ANSI/ASME B31G
- NG18 Surface Flaw Equation
- Modified B31G - Effective Area (RESTRENG),Kiefner
- Modified B31G- 0.85dL Area
- Bai & Bea (1997)

Procedure For Analysis of Corroded Pipe Strength: ASME, B31G



Problems Associated With The B31G Criteria

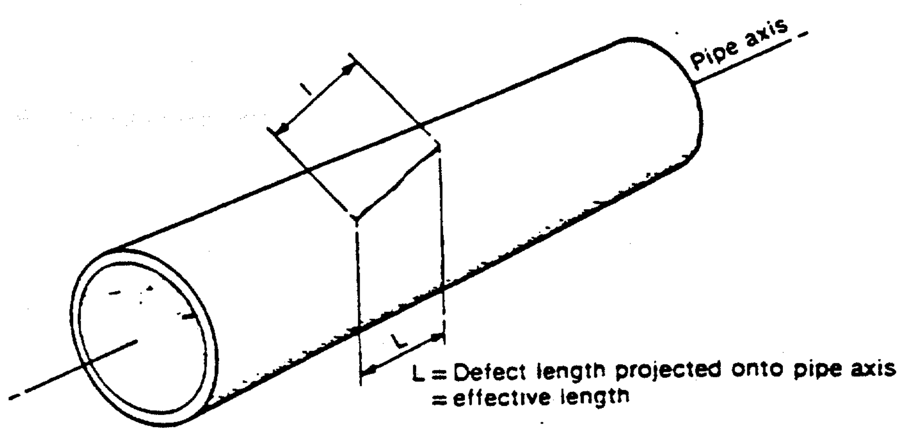
- Excess Conservatism
- Cannot Be Applied

  1- Spiral Corrosion

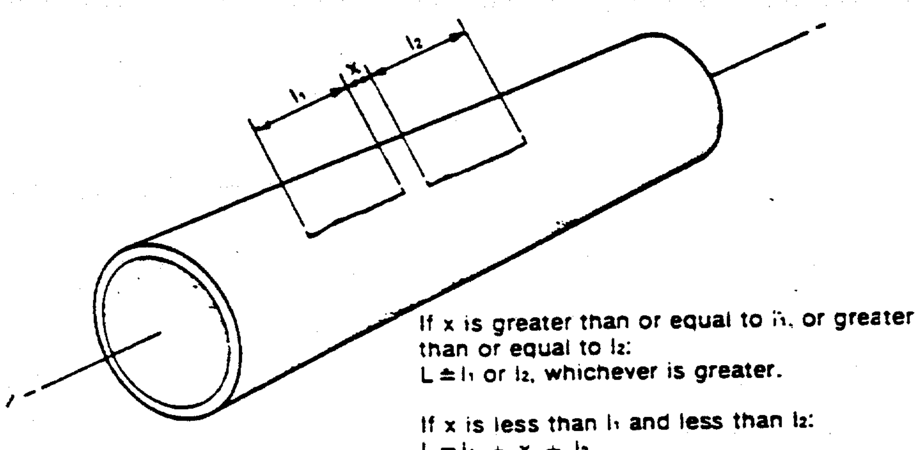
  2- Pits/Grooves Interaction

  3- Corrosion in Welds
- Ignores Beneficial Effects of Closely Separated Pits

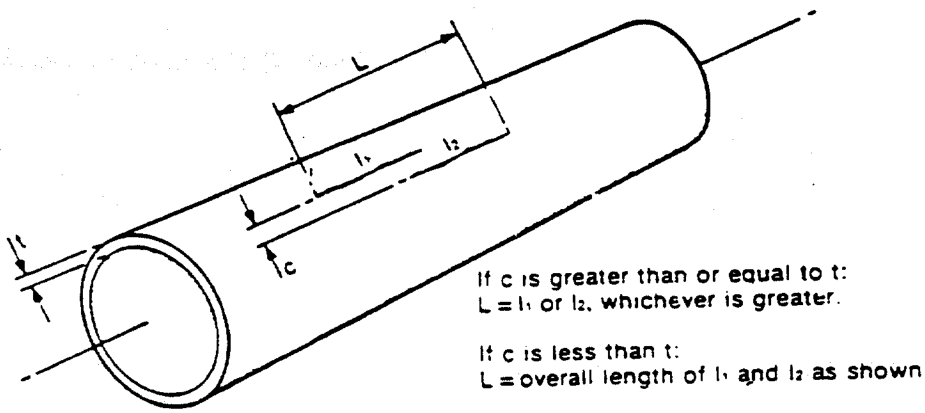
Effective Length and Interaction of Longitudinal Grooves (After Fig.15 of British Gas Standards BGC/PS/P11)



a) Defects inclined to pipe axis

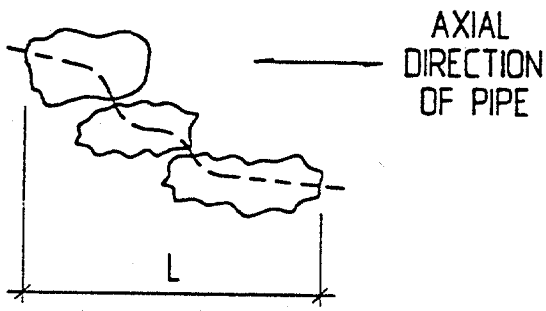


b) In-line defects

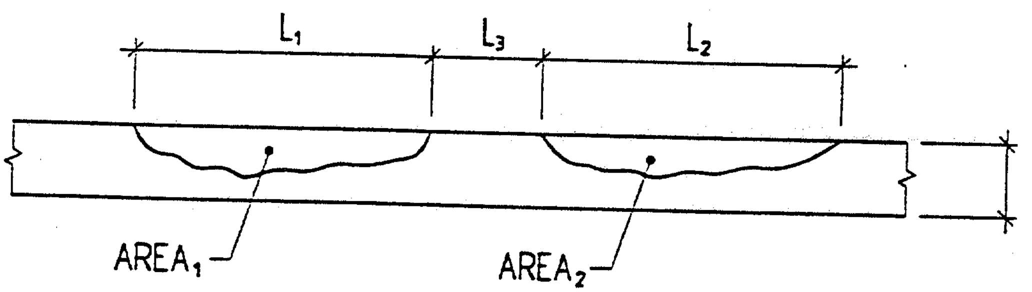


c) Circumferentially spaced defects

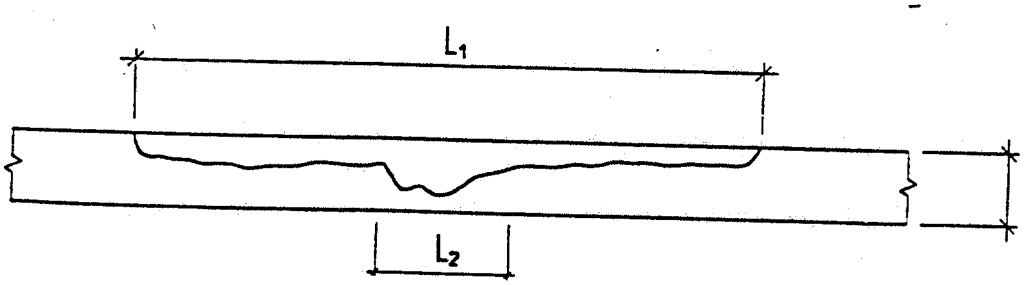
Closely Separated Corrosion Pits



(a) Closely Spaced Pits

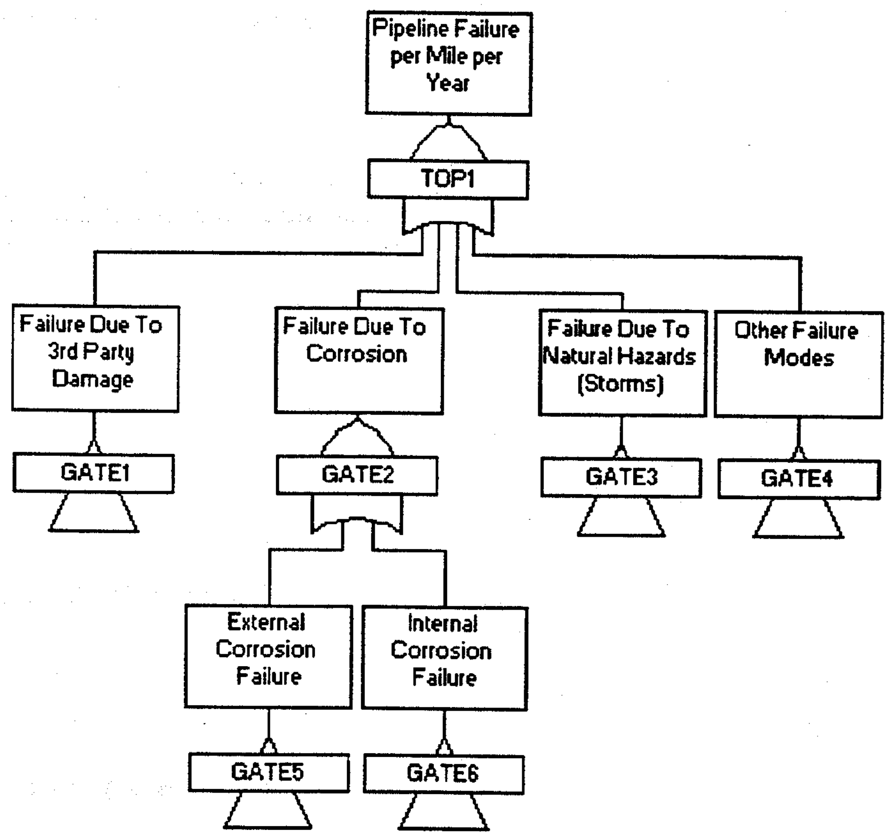


(b) Longitudinally Oriented Pits

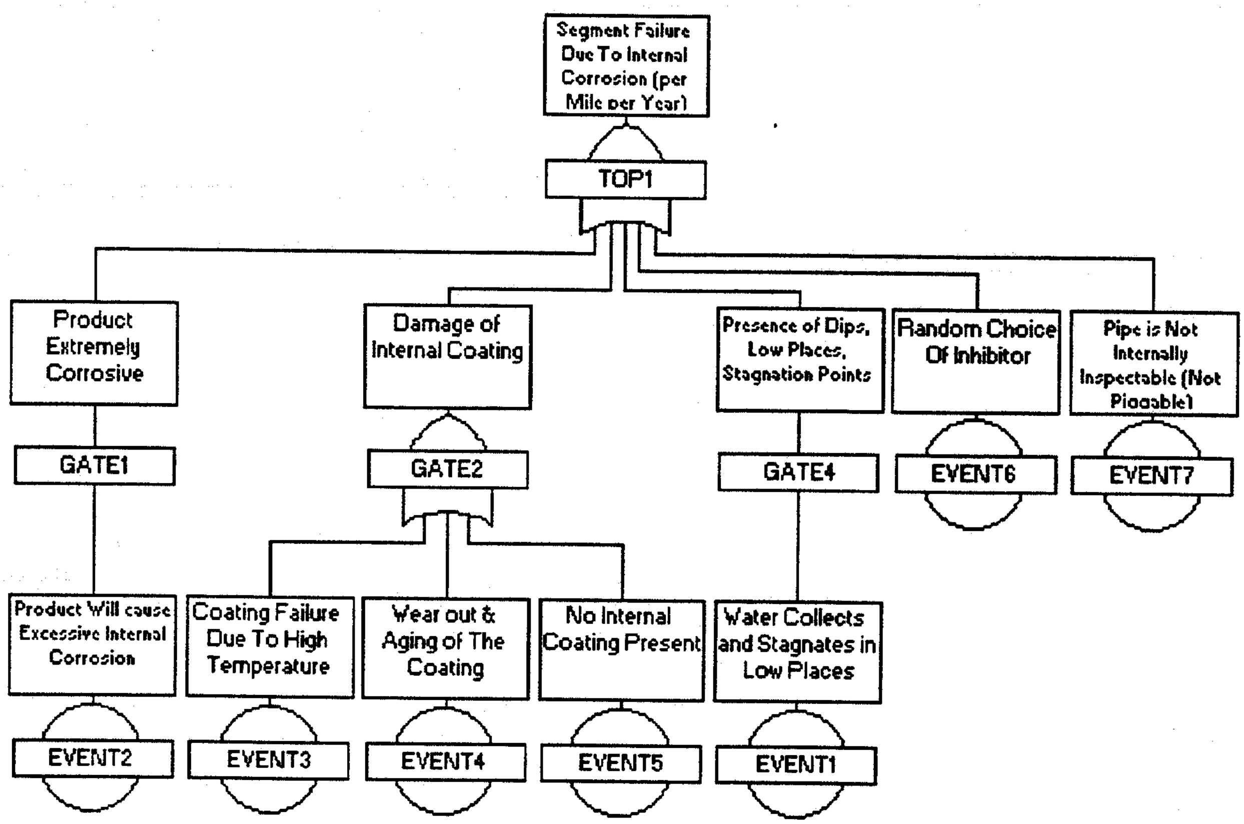


(c) Parallel Longitudinal Pits

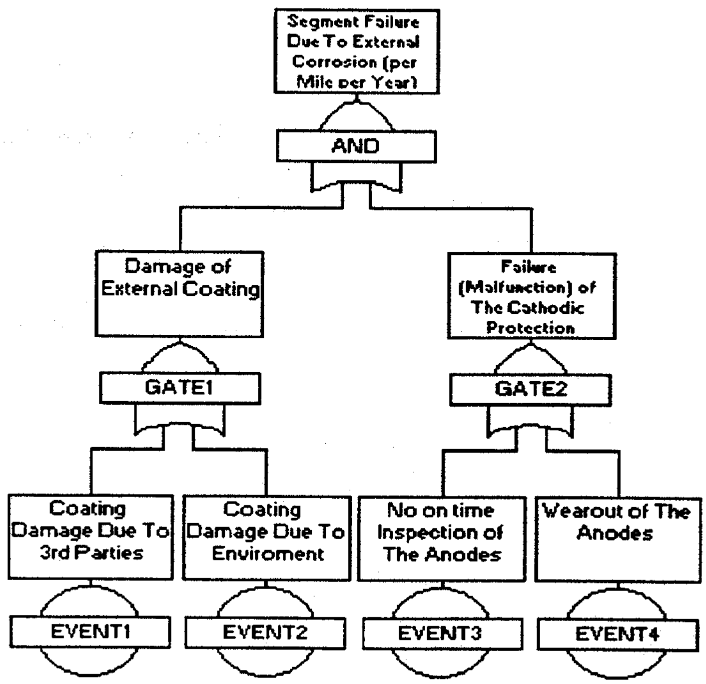
Fault Tree :Offshore Pipeline Segment Different Failure Modes



Fault Tree :Offshore Pipeline Segment Internal Corrosion

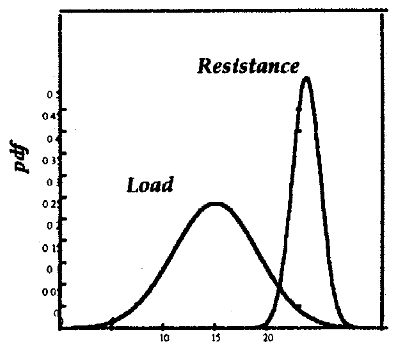


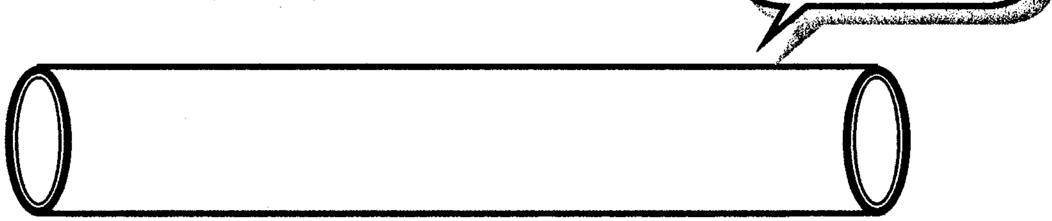
Fault Tree :Offshore Pipeline Segment External Corrosion



Quantitative Assessment of Failure Probability

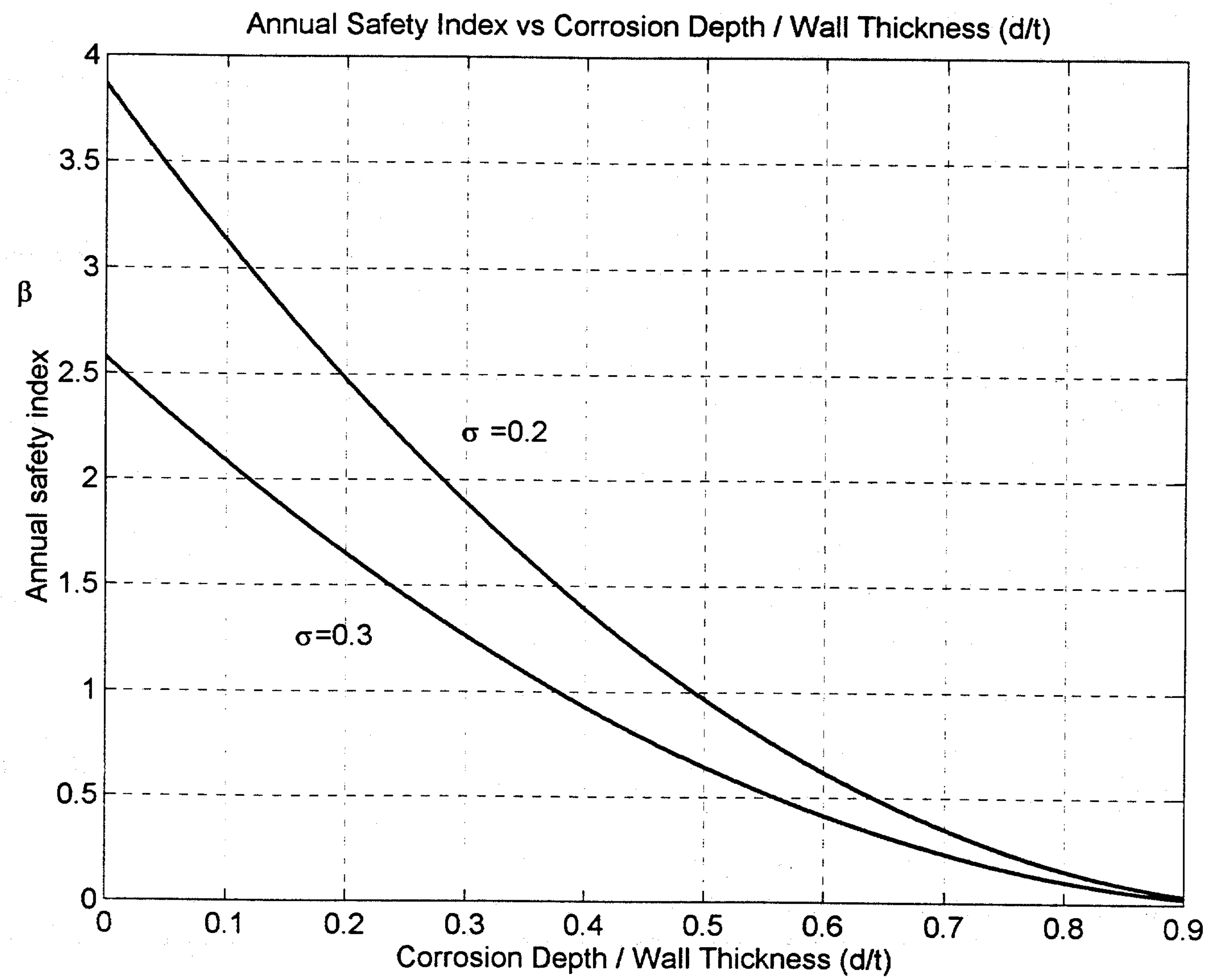
Quantitatve Determination of Probability of Failure



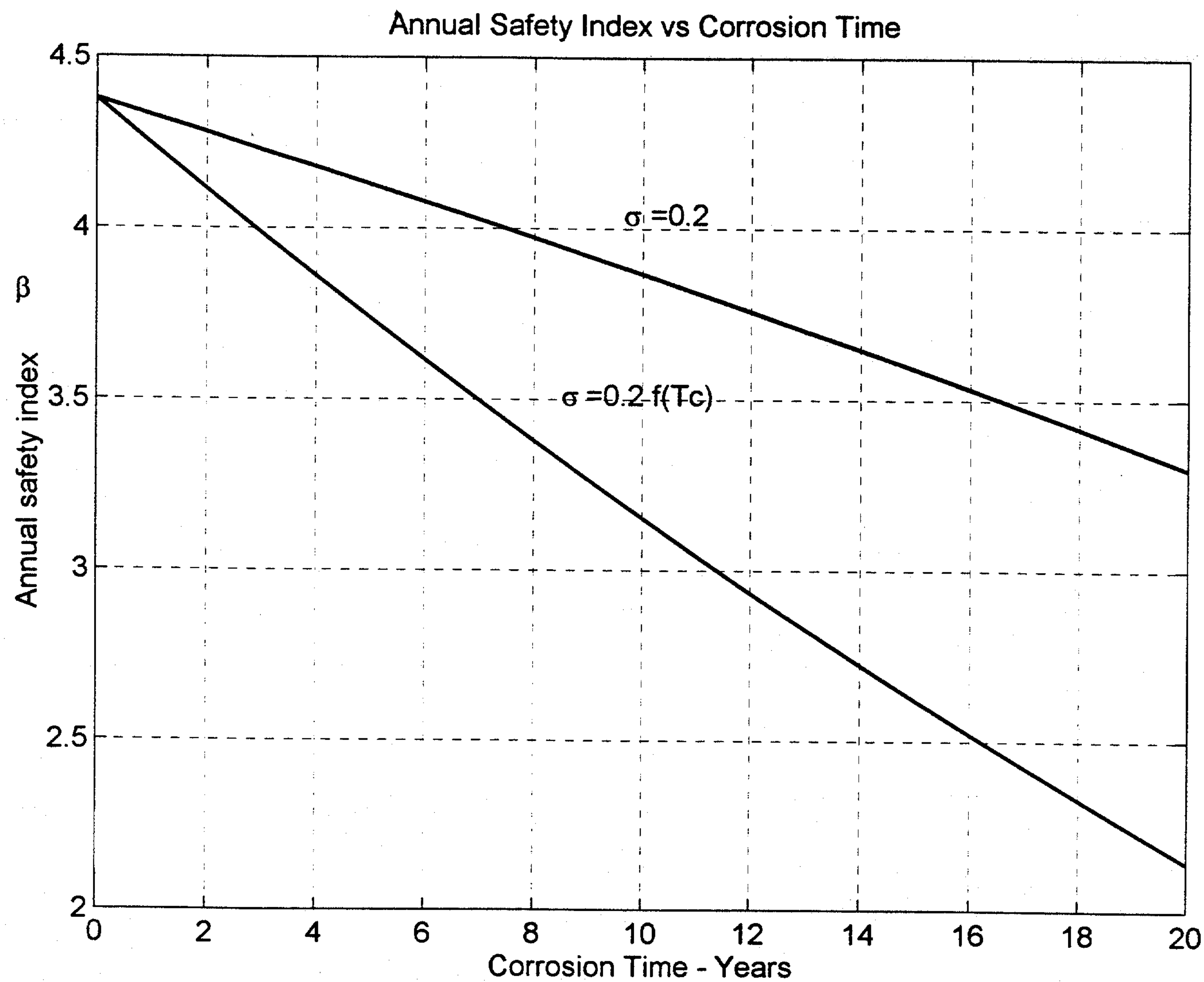


- Need to know
Limit state function
Probability distibution of Load
Probability distibution of Strength

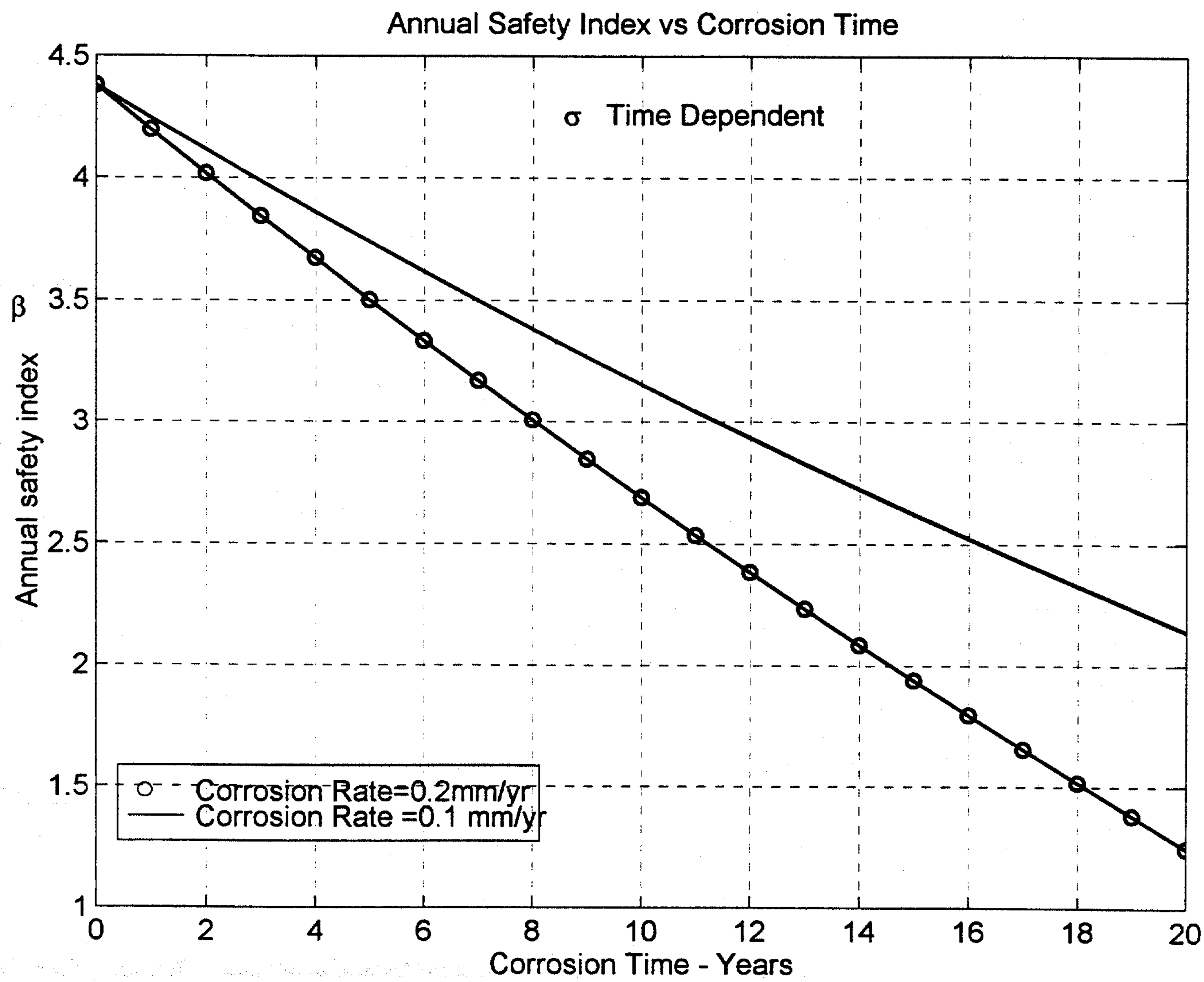
Effect of Metal Loss On Safety Index
Generalized Model: Bea



Annual Safety Index Vs Corrosion Time: Time Dependent Uncertainty Generalized Model: Bea



Annual Safety Index Vs Corrosion Time: Effect of Corrosion Rate Generalized Model: Bea



Summary & Conclusions

- A Simplified procedure has been developed for the reliability assessment of piggable pipes. The approach reduces computing time and resources.
- Reliability as a function of time for a locally corroded pipe can be calculated.
- Calibration and Verification of quantitative assessment using actual case studies. Results using this algoritm will be compared using detailed reliability calculations using FORM, SORM.

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